FRESH AIR AND VENTILATION

C.-E.A.WINSLOW

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FRESH AIR AND VENTILATION

VENTILATION: *Report of the New York State Commission*

This report is the result of nearly five years of comprehensive study of the whole problem of ventilation from the theoretical and practical points of view, by a body of six first rank biologists, physicians, public health experts, psychologists and ventilation engineers.

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FRESH AIR AND VENTILATION

BY

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NEW YORK

E. P. DUTTON & COMPANY

681 FIFTH AVENUE

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Printed in the United States of America

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INTRODUCTION

During the past twenty years our conception of what constitutes good ventilation, and our knowledge as to the best methods of securing satisfactory atmospheric conditions in home, school, office, and factory have radically changed. Experiments conducted during these two decades in Germany, in England, and in the United States, culminating in the exhaustive report of the New York State Commission on Ventilation,[1] have made out an overwhelming case for the revision of earlier viewpoints in regard to this important health problem.

Yet mistaken conceptions as to the objects and methods of ventilation persist on every hand and are embodied in legal form (as regards school house construction) in half the states of the Union.

1 Winslow, C.-E. A., Kimball, D. D., Lee, F. S., Miller, J. A., Phelps, E. B., Thorndike, E. L., *Ventilation: Report of the New York State Commission on Ventilation.* E. P. Dutton & Company, New York, 1923.

This situation is perhaps not surprising, in view of the fact that the newer knowledge in regard to ventilation is for the most part buried in scientific periodicals or in costly and technical monographs like the New York State Commission report. Professor J. R. McLure has recently done a very real service in preparing an admirable brief analysis of the bearings of recent advances upon the practice of school ventilation.[2] A clear presentation of the whole subject to the general reader, rather than to the physician, the engineer or the school superintendent, alone, has hitherto been lacking. The present volume is designed to fill this need, by presenting in broad outline the modern conception of what good ventilation is, and how we can secure it under varying conditions, in the light of recent researches, particularly those of the New York State Commission. Further details and exhaustive citations of original literature will be found in the full report of the commission itself and in the McLure monograph cited above. The attempt has been made to give in the following pages only such general conclusions as will be of value to the average man or woman in main-

[2] McLure, J. R., *The Ventilation of School Buildings.* Teachers College, Columbia University, Contributions to Education, No. 157, New York, 1924.

taining in his immediate environment such atmospheric conditions as will make for comfort, efficiency, and health.

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NEW HAVEN, CONN.
December, 1925.

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CHAPTER I

RELATIONS OF THE ATMOSPHERE TO HUMAN HEALTH AND COMFORT[1]

Air and Health

WHEN the wise king of the Hebrews sought to express the fundamental unity of the problems which confront each human life, he began with the atmosphere. "When I was born," he says, "I drew in the common air, and fell upon the earth, which is of like nature, and the first voice which I uttered was crying, as all others do." "The common air" is indeed the basic condition of our existence, controlling it in more ways than are yet fully realized. The atmosphere in its relations to human health and comfort seems therefore a topic

[1] This chapter is based upon an address delivered by the author before the Sanitary Section of the American Society of Civil Engineers in January, 1925; published in the Transactions of the Society.

which deserves the serious consideration of all who are intelligently interested in the promotion of the public health and welfare.

The basic conditions of life are in fact relatively simple. From the amœba to man, from the bacterium to the oak tree, the life process depends upon at least five essential factors, each present to an extent above a certain minimum and in general below a certain maximum. The five positive essentials are:

1. Food (including under this term regulative mineral salts)
2. Oxygen
3. Water
4. Temperature
5. Light

In addition to these positive essentials there must be freedom from

1. Mechanical injury
2. Toxic chemical substances
3. The attacks of hostile living beings, predatory or parasitic

The list is obviously not a logically com-

plete and perfect one. We shall shortly refer to one factor, that of atmospheric pressure, which is omitted from the scheme. The list includes, however, all but a minor fraction of those influences which under actual conditions affect the vital processes of animals and plants. It is of interest to note that, so far as man is concerned, in all but one of the life-factors noted, the atmosphere plays a more or less important role. Food we do not derive directly from the air about us, although our supply of plant food depends indirectly upon atmospheric nitrogen, and the prevalence of goiter in certain regions is correlated with the presence or absence of iodine salts blown inland from the sea. Oxygen, temperature, light and moisture as they affect the human body are directly related to atmospheric conditions; while the air may bear with it physically injurious dust particles, toxic gases, and under certain conditions the microbes of disease.

Composition and Characteristics of the Atmosphere

Before proceeding to discuss the more significant deviations from normal atmospheric conditions, as they affect our health and com-

fort, it will be desirable to recall for a moment what these normal conditions are—to which the human body is presumably more or less perfectly adapted.

The atmosphere of the earth is a layer of gases, of continuously decreasing density as one passes outward from the surface of the earth itself, and of varying composition when one reaches a distance where the decrease of gravitational force is so great as to show a marked differential effect upon its various constituents. Taking the atmosphere as a whole, it has been estimated that it is made up of nearly four million billion tons of nitrogen (73 per cent by weight), over one million billion tons of oxygen (23 per cent by weight), nearly 160,000 billion tons of argon and other inert gases (3 per cent by weight), and over 50,000 billion tons of water vapor (1 per cent by weight). Since water vapor is so highly variable a constituent, it is usually omitted from statements of the normal composition of the atmosphere; and this normal composition, at or near the surface of the earth, may be stated in the usual form as nitrogen, 78.1 per cent by volume, oxygen 20.9 per cent by volume, and argon .9 per cent by volume. Carbon dioxide is normally pres-

ent to the amount of .03 per cent and the inert gases other than argon (neon, helium, krypton, xenon) in still smaller proportions.

The constancy of the relation maintained between the four principal gaseous constituents of the atmosphere is a striking phenomenon. Nitrogen and argon, being relatively inert, might be expected to show but slight variation. Oxygen, on the other hand, is constantly being removed by the respiratory action of plants and animals and by processes of combustion and is constantly being contributed by the processes which go on in the green parts of plants during the daytime. Carbon dioxide is being consumed in these processes of plant growth and in the secretion of calcareous skeletons by various animals; while it is produced by respiration, by combustion, and by volcanic action and other subterranean processes. The extent of these changes may be suggested by the calculation that one hectare of oat field or forest (about two-and-a-half acres) consumes in an average summer season about 11,000 kilograms of carbon dioxide and gives off some 8000 kilograms of oxygen. These changes produced by one hectare of agricultural land during the summer would be just about balanced by the re-

spiratory activity of 32 human beings, during the whole year.

In connection with carbon dioxide, at least, the waters of the ocean exert an important regulative influence, dissolving in the form of bicarbonates any excess of the gas and yielding it up again as carbonic acid when the partial pressure in the air above decreases. As a net result of these complex processes, the proportion of oxygen in winter or summer, in town or country and even in the interior of dwellings rarely varies, near the surface of the earth, beyond the extreme limits of 20 and 21 per cent of the atmosphere by volume; while the variations in carbon dioxide, as will be pointed out later on, are somewhat wider.

Atmospheric moisture, on the other hand, varies greatly, from exceedingly small proportions to a point of approximate saturation. The saturation point itself depends directly upon the temperature of the atmosphere. Air at 0° F. will hold only .5 grain of water vapor per cubic foot; at 20° F. the amount increases to 1.2 grains; at 32° F. to 2.1 grains, at 68° F. to 7.5 grains, and at 98° F. to 18.7 grains. Thus there is actually more moisture per cubic foot in air at 80° F. when it is 20 per cent saturated than in air at 35° F. when 80 per

cent saturated; but the warmer air of lower relative humidity will be much more avid in absorbing moisture from the body or other moist surfaces and will thus be much more drying in its physiological effects. Desert air and the air of heated rooms in cold climates may fall as low as 10 per cent of their potential saturation value.

In addition to its various gaseous constituents the atmosphere usually contains a greater or less proportion of minute suspended particles in the form of dust, the significance of which will be discussed in a subsequent paragraph; and finally in even the briefest review of the composition of the atmosphere we must mention living micro-organisms, present only in very small numbers in pure outdoor air, as Pasteur demonstrated when he opened his flasks of putrescible liquid upon the Mer de Glace, but often rising to hundreds per cubic foot indoors and, when considerable contaminated dust is present, even to much higher figures.

The Physiological Effects of Atmospheric Pressure

The first problem which naturally suggests itself in connection with the relation of the

atmosphere to human health and comfort is that of the influence of quantitative changes in concentration due to differences in atmospheric pressure. The pressure itself is apparently not a factor of primary importance, although under certain circumstances sudden changes in pressure may produce serious and even fatal results. In the construction of tunnels and the laying of foundations the workers in caissons are exposed to pressures which may exceed three or four atmospheres. While under an excess pressure of even 50 pounds per square inch no marked discomfort is experienced; but on return to normal pressure, if this return be made too rapidly, caisson disease or compressed air illness frequently results. In the building of the tunnels under the East River 3692 attacks of compressed air illness with 20 deaths were recorded in a group of 10,000 employees. The pathology of this disease appears to be a relatively simple one. Under abnormal pressure an excess of the atmospheric gases goes into solution in the blood; when this pressure is suddenly released there results a direct liberation within the blood vessels or tissues of bubbles of nitrogen gas with inevitable mechanical injury. This condition can, of course, be controlled by regu-

lated and gradual decompression. Far more important than the direct effect of such variations in atmospheric pressure are the indirect effects due to changes in oxygen concentration. Oxygen is after all the most essential contribution of the atmosphere to human health and comfort; and the precursors of Galen, when they taught that the arteries were ducts for the transportation of air, were after all very close to a physiological truth. As one passes upward from sea-level the reduction in atmospheric pressure soon produces a reduction in partial pressure of oxygen which has real physiological significance. Thus at 5000 feet above sea-level the partial pressure of oxygen corresponds to 17.5 per cent of the atmosphere at sea-level (instead of the normal 21 per cent). Even at this point a few individuals begin to show an accelerated heart-beat. Many famous health resorts are, however, situated at an altitude of 5000 feet, with a partial pressure of oxygen far below that of the most crowded room.

At 10,000 feet the concentration of oxygen is only 14.2 per cent of a sea-level atmosphere and symptoms are more marked and more general. My colleague, Professor Yandell Henderson, with the English physiologists,

Douglas and Haldane, made an important series of studies of the effects of such conditions on Pike's Peak in Colorado. Here, the partial pressure of oxygen present corresponds to about 13 per cent at ordinary atmospheric pressure. Under these conditions there are distinct symptoms of mountain sickness, as a result of oxygen deficiency, blueness of lips and face, loss of appetite, nausea and vomiting, intestinal disturbances, headache, fainting, periodic breathing, and great difficulty in getting breath on exertion. But even here, with the equivalent of only 13 per cent of oxygen, after a few days the symptoms began to lessen, and after a few weeks of acclimatization the extreme conditions disappeared, although periodic breathing was still occasionally observed, and lips became blue on vigorous exertion. The investigators believed that at least three things had happened in this adaptation: In the first place the cells lining the alveoli of the lungs had acquired the power of secreting oxygen one way and carbon dioxide the other, more vigorously for the same gaseous pressure than they would under ordinary conditions. In the second place, the alkalinity of the blood had changed so as to stimulate the respiratory center with a less amount of carbon dioxide.

And finally the hemoglobin had increased so as to supply the tissues more readily with the needed oxygen. Many people live vigorous and active lives under conditions such as this; the great city of Potosi in the Andes, for example, has an oxygen concentration very close to that of Pike's Peak.

Beyond 13,000 feet of altitude, with oxygen concentration below 12.7 per cent, mountain sickness becomes a much more serious matter. The gallant struggle to conquer Mt. Everest, which we have followed with such eager interest during the past few years, is first and foremost a struggle against oxygen starvation and its success will probably depend upon devising means for transporting oxygen apparatus for the use of the climbers who are to accomplish the last few hundred feet of rock which still tower unconquered into the sky. For the aviator, too, this problem is of the most pressing import. Bombing and observation planes are able to fly for hours at heights of 12,000 feet or more and pursuit or battleplanes not infrequently reach altitudes of 20,000 feet. The so-called air staleness among pilots is merely mountain sickness in a pronounced form and the studies made by the Medical Research Laboratory of the Air Service at

Mineola along lines outlined by Henderson, have shown how the worst effects of this malady may be avoided by the selection of pilots shown by specially devised tests to be peculiarly resistant to low oxygen pressure.

Chemical and Thermal Problems of Ventilation

On mountain tops, and in the vast spaces of the empyrean where the airman goes, the most serious atmospheric hazard is the lack of oxygen. At the other extreme of human pioneering—in the bowels of the earth—the same danger is met in a different form. In the deep parts of mines, and in old wells, the normal atmosphere may be replaced to so great an extent by carbon dioxide that men entering such places may perish of oxygen starvation. On the surface of the earth itself, however, in the normal haunts of man, the problem of oxygen content need give us no concern. Even in the worst ventilated classroom or auditorium or workshop the percentage of oxygen in the atmosphere never falls below 20 per cent on account of leakage through cracks and the rapid diffusion which takes place even through solid walls and ceilings. Lavoisier, as early as 1777, showed by animal experiments that the symptoms experienced in a badly

ventilated room could not be attributed to oxygen deficiency. It is only when the partial pressure of oxygen falls from its normal 21 per cent of an atmosphere to a value of 16 per cent or less that important physiological reactions are involved.

Lavoisier himself believed that the evil effects of vitiated air were due to the toxic effects of carbon dioxide and this view was held by physiologists for about a hundred years. It was Pettenkofer, in 1862, who first clearly enunciated a third theory, that the influence of bad air was due to the presence of toxic organic substances excreted into the atmosphere from the human body. In his criticisms of the carbon dioxide theory at least, Pettenkofer has been supported by all subsequent observers. The presence of carbon dioxide is of fundamental importance in relation to human life, since it is the concentration of this gas in the blood which determines the activity of the respiratory mechanism. In the absence of carbon dioxide, breathing would cease and asphyxia result, and the increased depth and rate of respiration after vigorous physical exercise is the direct result of increased carbon dioxide in the blood stream. An atmospheric concentration of 2 per cent of this gas causes

an automatic increase of about 50 per cent in depth and rate of breathing, just such as occurs with moderate exercise; and in breweries and mines such concentrations are actually borne with no appreciable discomfort. In the worst ventilated rooms, however, carbon dioxide content rises only from the normal .03 per cent to about .5 per cent of an atmosphere and such a change as this is well below the threshold of physiological significance.

Pettenkofer's alternative hypothesis of toxic organic substances in respired air has, on the other hand, proved as untenable as the carbon dioxide theory in explanation of the physiological phenomena which follow exposure to the air of badly ventilated rooms—a problem discussed in detail in a succeeding chapter. As will there be pointed out, the unfavorable effects of such air are in reality primarily due not to organic poisons but to the effect upon the human body of high temperature, abnormal humidity, and lack of air movement. As Professor F. S. Lee has summarized the situation in epigrammatic form, "The physiological problems of ordinary ventilation have ceased to be chemical and pulmonary, and have become physical and cutaneous."

The Physiological Effects of Sunlight

We have briefly reviewed the effects of atmospheric oxygen upon the human body; and the influences of temperature and moisture will be fully treated in Chapter II. Of the four primary physiological relationships of the aerial envelope there remains only that of sunlight to be considered here.

The value of sunlight as an adjunct to health has been stressed by hygienists ever since the days of the Greeks. In the medieval code of the School of Salernum prominent place is given to the admonition,

> Let air you breathe be sunny, clear and light,
> Free from disease, or cesspool's fetid blight.

Soft coal was introduced into London about the end of the thirteenth century and almost at once an agitation against the "smoke nuisance" began, leading even in the reign of Edward I to a prohibition of the use of soft coal during the sessions of Parliament. English authorities have devoted much attention to this problem during the past few years and have demonstrated the astounding fact that between 80 and 400 tons of solid matter per

annum are deposited from the air of English cities on every square mile of territory. In Manchester, Glasgow, and Leeds it has been shown that the average amount of winter sunlight is diminished about 40 per cent as compared with adjacent rural districts, while Besson reports that the smoke of Paris causes a reduction in sunlight of 15 to 25 per cent as far as 10 kilometers from the city.

In our own country the Cleveland Chamber of Commerce has estimated the financial loss due to smoke at $12 per capita per annum.

So far as effects upon health are concerned, it must be remembered that the whole theory of the beneficial effects of sunlight has rested in the past on a purely empirical basis. Various authors reported statistical studies indicating that the death rate was higher in smoky cities than in rural districts and in the smoky winter season than in summer; but conclusions drawn from such analyses as to the harmful effect of a smoky atmosphere *per se* were clearly fallacious. Too many of what the late Professor Whipple called "concealed classifications" were involved for any sound distinction between the influence of smoke and the influences of urban life or of the winter season as a whole. Even the revival of the

cult of Apollo by Rollier and his Swiss colleagues in the treatment of tuberculosis by exposure to sunlight rested on purely clinical observations which were not altogether convincing, in view of the fact that tuberculosis patients who live a hygienic life so generally recover whatever other special treatment they receive. Of sound and incontrovertible experimental evidence as to the hygienic and therapeutic value of sunlight, we had really none until five years ago. The conscientious teacher of hygiene, when he came to such problems as that of the smoke nuisance, was forced to buttress his case by ingenious hypotheses as to the effect of soot in causing people to keep their windows closed or in leading them to form habits of personal uncleanness; but he was never quite happy about the matter.

When Huldschinsky, in 1919, showed that irradiation with sunlight or with the quartz mercury vapor lamp prevented and cured rickets, a new chapter in physiological science was opened. The work of Hess in New York, and of Park at Baltimore and New Haven has made it clear that rickets can be controlled by two apparently distinct agents—the administration of cod liver oil and irradiation—neither obviously related to the abnormalities of cal-

cium and phosphorus metabolism which characterize the disease in itself.

Now come Steenbock and Black and Hess with the demonstration that foods which do not in themselves possess anti-rachitic value may be endowed with such a value by exposure to ultra-violet light; so that the apparently independent action of sunlight and cod liver oil turns out as Park predicted to be truly an interdependent one. When we give cod liver oil to cure rickets, we are really administering "bottled sunlight."

For the practical hygienist the chief immediate point is that we have now at last a rational justification for our instinctive belief in the value of sunlight, a new ground for controlling the smoke nuisance, demanding sound building laws and advocating the outdoor life. The superiority of scientific knowledge over empiricism is well illustrated, however, by the fact that sunlight admitted through glass is robbed of its most valuable radiations and as Bovie has shown in his studies of diseases of fowls this problem may perhaps have to be solved by the use of windows made of fused quartz. Our fathers were right in believing that sunlight was a good thing; how it really acts and how its benefits can most practically

be secured we are just beginning to comprehend.

Bacteria in the Air

In addition to the normal and universal constituents of the atmosphere there are certain suspended materials generally present in greater or less amount, and among such suspended particles are living microbes of various sorts—to which much sanitary importance was attributed in the past. When Lister devised his first antiseptic spray in 1867, it was the microbes in the air which loomed largest in his mind as potential factors in wound infection, and the work of Pasteur demonstrated that so far as the decomposition of organic liquids was concerned the germs carried by air did indeed play a predominant role.

Since those microbes which are present in air are largely carried on minute dust particles, it is of interest to note that the bacterial content of dust is a considerable one. Kligler and the writer have found an average of about 50 million bacteria per gram in the dust of city streets and between 3 and 5 million in indoor dusts. Most of these bacteria are, of course, harmless saprophytes, but about 1 in 1000 of

the street dust microbes and 1 in 4000 of the indoor microbes was of an intestinal type, while 1 in 1000 of the street organisms and 1 in 200 of the indoor organisms was a member of the group of streptococci characteristic of the human mouth. Five to 20 tubercle bacilli per gram have been found in the dust from places occupied by careless tuberculous patients.

Of the dust which may be collected from floors and other surfaces, the amount which actually gets into the atmosphere is after all very small except when the dust is stirred up by dry sweeping or violent winds. The actual bacterial content of the air is, therefore, generally low. In one of Pasteur's classic experiments he opened sterile flasks of putrescible liquids (previously heated and sealed so as to contain a vacuum which would cause an inflow of air when they were opened) in various localities. Of 20 flasks thus exposed to normal country air at Arbois 8 showed the presence of micro-organisms; while of a similar series opened on the slopes of the lower Jura mountains only 5 spoiled, and of a third series exposed on the Mer de Glace 1 only became infected.

Browne and the writer have found in coun-

try air an average of 56 microbes per cubic foot, in city streets an average of 72, in the indoor air of offices and schools 95, and in factories 113. Streptococci characteristic of specific mouth pollution were present to the number of 11-12 per 100 cubic feet in outdoor air, 22 per 100 cubic feet in offices, 30 in schools, and 43 in factories.

Such a bacterial content as this appears to have no important practical significance and so far as the transmission of disease microbes through the general medium of the atmosphere is concerned, epidemiological evidence is overwhelmingly negative. It has been made clear that even the widely distributed pus organisms get into wounds not from the air but from the skin of the patients or the instrument which produced the wound or other objects which have come in contact with it; while the experience of well-managed hospitals has shown that it is possible to care for various communicable diseases in a single open ward without serious danger of cross-infection, if aseptic technique be rigorously maintained.

Within a range of a few feet the direct discharge of mouth spray from an infected person is, of course, a real and important danger. Trillat in Paris has shown that bacteria sus-

pended in moist droplets penetrate a cotton filter far more readily than when aspirated in a dry powder and that bacteria when inhaled by animals in droplets are drawn into the deepest parts of the lungs very quickly, while when borne by dry dust they are almost completely caught and held by the moist mucous membranes of the upper nose and throat—a phenomenon which may perhaps be related to the electrical charges borne by the respective types of particles. The whole problem of droplet infection is, however, more nearly related to contact than to general atmospheric pollution. The mouth spray is a fine rain which settles quickly to the ground, not a vapor which disseminates itself through the air; and Robinson and the writer have found that the vast majority of the bacteria discharged in coughing, sneezing, and loud speaking disappear from the air beyond a radius of a few feet.

Problems of Atmospheric Dust

The microbes of the atmosphere, of course, constitute but a minute fraction of the suspended matter which it normally carries. Lifeless organic particles and finely divided inorganic matter are present almost every-

where and are made manifest by the reflection of light as the dancing motes in a sunbeam. Such particles play an important part in promoting the formation of fog and rain, serving as nuclei for the condensation of atmospheric moisture; and to the reduction in the amount of aerial dust is due the clearness of the air after a heavy storm. As Tyndall showed in his classic experiments, the larger of these particles will so completely disappear from the air in a closed box with glycerin-covered walls that a beam of light passed through the box becomes entirely invisible.

The sources of this atmospheric dust are various. Part of it is raised from dry surfaces by the wind like that borne into the city of Pekin from the Gobi Desert. Part comes from volcanic eruptions. The dust discharged during the great eruption of Krakatoa remained for several years in the atmosphere and traveled many times around the globe. Another important fraction of aerial dust is of extra-terrestrial origin since besides the 20,000,000 meteorites a day which appear as "shooting stars," finer "mineral particles of foreign source are constantly pouring through our atmosphere in the form of a dry and invisible rain."

The number of dust particles which we detect in the examination of air depends very largely upon the method of sampling and analysis. Optical methods, which depend on the depth of fog produced by condensation of moisture on the dust particles in a vacuum tube, may show billions of particles per cubic foot in ordinarily clear air. For practical purposes it seems probable that the more minute of the motes in the sunbeam are of little practical importance and most methods of examination depend on the collection of dust particles by a water-spray or by impingement in water or on a vaselined plate and on the counting of the particles under the microscope—a procedure which gives us in the main those particles with a diameter between 1 and 10 microns. Counts made with the Palmer water-spray apparatus have shown less than 10,000 particles per cubic foot (and less than .001 mg. per cubic foot) in country air after a rain and 23,000 particles outside the fifty-eighth floor of the Woolworth Building; as compared with 118,000 particles per cubic foot in the street outside the Woolworth Building and about the same number (100,000) in ordinary indoor air. In dusty factories, on the other hand, the number of dust particles may rise to millions.

In an abrasive factory at Niagara Falls the average of nine air samples gave the astounding result of 159,779,000 particles (7.805 mg.) of dust per cubic foot of air.

The influence of atmospheric dust upon health varies even more with the kind than with the gross amount of dust which may be present. This problem will be discussed in some detail in Chapter IV, with the related question of the hazard which exists in factories, workshops, garages, and even in homes, from the presence of poisonous fumes and gases produced by industrial processes or by imperfect combustion.

Odors and Health

The theory that miasmatic vapors of the atmosphere were the chief causes of epidemic disease dates back to the days when Hippocrates lighted fires in the streets of Athens to purify the air and put a stop to the plague. This view persisted as a dominant factor in medical teaching for fifteen hundred years, and when the medical faculty of Paris reported on the epidemic of plague which ravaged Paris in 1348, they attributed the disease, as Hippocrates did, primarily to

malign conjunctions of the planets and, secondarily and immediately, to a corrupted atmosphere. One paragraph of this famous document reads as follows:

Although there is danger of pestilential sickness from corrupted water and food as is observed in times of famine and drought, yet there is greater danger of sickness from the corruption of the atmosphere. For bad air is more injurious than food or drink on account of the velocity with which it penetrates to heart and lungs with its evil qualities. We believe that the present epidemic or plague arises immediately from air not only qualitatively altered but corrupted in its substance. By this I mean that normal air existing in its clear and pure state cannot decay or become corrupted unless from the admixture of evil vapors.

Because, therefore, many corrupt vapors from the aforesaid conjunction from earth and water have been raised up and disseminated through the air by the blasts of the heavy and turbid southerly winds, on account of extraneous humid vapors which they bring or have brought with them the air itself has become corrupted. Air thus corrupted necessarily penetrating to the heart corrupts the substance of the heart according to its nature, and decays the surrounding tissues in similar manner—finally according to nature extends and corrupts the principle of life. This is the immediate cause of the present epidemic.

Even fifty years ago it was still held that such diseases as typhoid fever and cholera

were pythogenic in origin—that is, that their causative miasms were generated by the decomposition of organic filth. Murchison, one of the leading physicians of his time, taught in 1873 that such fevers "may be generated independently of a previous case by fermentation of fæcal, and perhaps other, forms of organic matter" and that in these diseases "the poison is not, like that of smallpox, given off from the body in a virulent form, but is developed by the decomposition of the excreta after their discharge." Dr. John H. Griscom of New York, in his book on *The Uses and Abuses of Air* (1854), displays an even more exact knowledge of the etiology of such diseases. He says, on what authority I know not, "Dr. Carmichael Smith discovered that the vapors of nitrous acid neutralize and render harmless the typhus miasm, which he ascertained to be sulphuret of ammonia, and on the utility of this discovery being duly tested and confirmed, a sum of 5000 pounds was voted to him by the British Parliament, as a national donation."

The development of the science of bacteriology gradually dispelled these miasms, which certainly existed as corrupting influences in the thoughts of men, even if they did not in-

fluence their physical health; and we know today that the communicable diseases are no more influenced by atmospheric vapors than by the conjunctions of the stars. The fear of noxious odors is, however, very deeply implanted in human psychology and even after the germ theory was well established the old terror persisted under a new guise—that of the alleged predisposing influence of organic emanations—morbific matter, anthropotoxin —in the atmosphere.

How this specter was dispelled and how it has been shown that the ordinary effects of the air of a badly ventilated room are due to physical rather than chemical factors will be described in Chapter II. Fortunately, however, we are safeguarded from a too arbitrary and dogmatic dismissal of the whole problem of bad smells to the limbo of chimeras by the experiments of the New York State Commission on Ventilation; and it is always a relief to find at least some experimental basis for widely held beliefs, since empirical opinion is on the whole so likely to prove itself in the long run not without justification. These New York studies indicated that the stale air of an occupied room, even when artificially controlled from the standpoint of

temperature and humidity, but containing a very high concentration of the chemical products associated with the "body odor," did have two slight but distinctly measurable effects upon human behaviour. Subjects exposed to such stale air showed a definite disinclination to physical activity, accomplishing 9 per cent less work in stale than in fresh air; and they showed a marked diminution in appetite, the amount of food eaten at luncheon served in the stale air being from 4 to 14 per cent less than in fresh air of the same temperature and humidity. Experiments in my laboratories at Yale have similarly shown that the growth of young guinea pigs is quite definitely retarded by exposure to the odors from decomposing organic matter.

As to the discomfort and at least minor derangements of health produced by more obvious offensive odors there can, of course, be no question. The most exhaustive study of this problem with which I am familiar is contained in a "Special Report of the Rhode Island State Board of Health on the Cause, Prevalence and Effect of Offensive Odors in Providence, Cranston, East Providence, and Warwick during 1921." The odors in question were produced by the burning of high

sulphur fuel oils and by the distillation and refining of petroleum. Their influence extended for distances of three to four miles from the plants at which they originated and was felt by a population of 126,000 people. Record was obtained of definite symptoms affecting 96 persons, such as irritation of the throat, suffocation or choking sensation, nausea, headache, dizziness, and malaise, reasonably attributed to the odors in question. Mr. S. D. Gage, the chemist and engineer in charge of this investigation, discusses the situation as follows:

When our investigation was first started, certain physicians and public health men with whom we discussed the matter expressed the opinion that the subject of offensive odors was not a health matter; that the effect, if any, was purely psychological. This is largely a question of the interpretation placed on the term health. With a very few exceptions the symptoms of the cases cited in the previous pages were temporary and not lasting. But, while the effect lasted, it was very real and in certain cases sufficiently severe to incapacitate the victim and of sufficient duration to interfere seriously with his regular avocation. In other words, it reduced his mental and physical efficiency for a greater or less period of time at intervals which were dependent on the frequency of recurrence of the odors. It is well recognized by physiologists that intense and offensive

odors may cause reflex actions affecting the nervous, digestive, and the secretory systems. Such reactions frequently repeated cannot help but have an unfavorable effect on the general health. Even if the effect is psychological rather than physiological, if the effects produced upon the system are the same, the ultimate effect on the health must be the same.

From the results of our own investigation we know that there are at least 96 persons who are or have been more or less seriously affected by these odors. From physicians have been received reports of 32 persons made ill and of 15 persons suffering from other diseases whose illness has been aggravated and perhaps their chance of recovery lessened from this cause. All or nearly all of these persons show a record of symptoms identical in character with those known to be caused by fumes or vapors of certain substances which from all available evidence are probable constituents of the odors which these persons have been forced to breathe at least a material portion of the time for a period of many months. The consensus of opinion among Rhode Island physicians, as expressed in their replies to our inquiry, is to the effect not only that the course of a number of diseases may be unfavorably affected by certain of the constituents of these odors, but also that the effect of these odors or fumes would be prejudicial to the continued good health of normal persons.

We may, therefore, conclude that while air does not as a rule bear the germs of disease and does not carry with it mysterious and specific organic poisons, an atmosphere laden

with offensive odors is not only objectionable on æsthetic and economic grounds, but may under certain circumstances constitute a real menace to the public health.

It is of primary importance, therefore, that sewage and garbage disposal plants, packing houses, and oil refineries should be so designed and operated as to minimize the discharge into the atmosphere of products of organic decomposition or of offensive fumes from the combustion and handling of odoriferous materials. The task is exceedingly difficult, when one is dealing with such substances as hydrogen sulfide, which the nose can detect when present to the extent of one gram in a million million cubic centimeters of air, or mercaptan, which is detected twenty-five times more readily than hydrogen sulfide. In the selection of processes for the disposal of sewage and garbage, the possibility of aerial nuisance must always be a determining factor; and where the production of offensive odors is unavoidable, the possibility of deodorization by the use of chlorine or in some other way should be given the most careful consideration.

CHAPTER II

WHAT CONSTITUTES GOOD VENTILATION

The Effects of Bad and Good Ventilation

THE general characteristics of the atmosphere; the qualitative and quantitative variations in its composition and their influence upon health; the physiological effects of sunlight; the problems of bacteria and dust and odors in the atmosphere—all these serve to form a background for the consideration of what is, after all, our most pressing practical problem —the problem of what actually constitutes good ventilation in the home, the school, the office, and the factory. It is in regard to this question that our views have changed so materially as a result of the new discoveries of the past twenty years.

It is important to emphasize first of all in any consideration of this subject that nothing in the recent work tends in the least to minimize the incontrovertible fact that bad ventilation does, in fact, exert the most profound

effects upon human health and comfort. In a crowded, ill-ventilated room we experience a feeling of dullness, sleepiness, and under more extreme conditions faintness and nausea; while there are several classic instances in which such conditions of the atmosphere have become so extreme as to result fatally. The most famous of these examples is that of the Black Hole of Calcutta, which Professor F. S. Lee has described in the following pregnant sentences:

On one of the hottest of the hot nights of British India, a little more than one hundred and fifty years ago, Siraj-Uddaula, a youthful merciless ruler of Bengal, caused to be confined within a small cell in Fort William 146 Englishmen whom he had that day captured in a siege of the city of Calcutta. The room was large enough to house comfortably but two persons. Its heavy door was bolted; its walls were pierced by two windows barred with iron, through which little air could enter. The night slowly passed away, and with the advent of the morning death had come to all but a score of the luckless company. A survivor has left an account of horrible happenings within the dungeon, of terrible strugglings of a steaming mass of sentient human bodies for the insufficient air. Within a few minutes after entrance every man was bathed in a wet perspiration and was searching for ways of escape from the stifling heat. Clothing was soon stripped off. Breathing became difficult. There were vain onslaughts on the windows; there

were vain efforts to force the door. Thirst grew intolerable and there were ravings for the water which the guards passed in between the bars, not from feelings of mercy, but only to witness in ghoulish glee the added struggles for impossible relief. Ungovernable confusion and turmoil and riot soon reigned. Men became delirious. If any found sufficient room to fall to the floor, it was only to fall to their death, for they were trampled upon, crushed, and buried beneath the fiercely desperate wave of frenzied humanity above. The strongest sought death, some by praying for the hastening of the end; some by heaping insults upon the guards to try to induce them to shoot. But all efforts for relief were in vain, until at last bodily and mental agony was followed by stupor. This tragedy of the Black Hole of Calcutta will ever remain as the most drastic demonstration in human history of the bondage of man to the air that surrounds him.

An almost equally famous instance of the acute effect of overcrowding is the accident which occurred on board the *Londonderry,* which left Sligo for Liverpool in December, 1848, with two hundred passengers. Lewes has described this tragedy in the following lines:

Stormy weather came on, and the captain ordered everyone to go below. The cabin for the steerage passengers was only 18 feet long, 11 feet wide, and 7 feet high. Into this small place the passengers were crowded; they would only have suffered inconvenience, if the

hatches had been left open; but the captain ordered these to be closed, and—for some reason not explained—he ordered a tarpaulin to be thrown over the entrance to the cabin, and fastened down. The wretched passengers were now condemned to breathe over and over again the same air. This soon became intolerable. Then occurred a horrible scene of frenzy and violence, amid the groans of the expiring and the curses of the more robust; this was stopped only by one of the men contriving to force his way on deck, and to alarm the mate, who was called to a fearful spectacle: seventy-two were already dead, and many were dying; their bodies were convulsed, the blood starting from their eyes, nostrils, and ears.

The beneficial effects of good air have been equally obvious to medical men from early times; and the gospel of fresh air has been crystallized into definite and effective form in the development of sanatorium treatment for tuberculosis during the past half century. Dr. Edward Trudeau went to Saranac in 1873 as a hopeless victim of consumption. All his friends were filled with horror at the idea of his going, practically alone, to die, as they believed, in the Adirondack wilderness, in a little town consisting of little more than a sawmill and half a dozen cabins, forty-two miles from a railroad. Dr. Trudeau did not die, however, during the winter of 1873, but grew very much better; and some ten years later,

as a result of his experience, he founded the Adirondack Cottage Sanatorium, which in its primitive form consisted of a single house in which, with great difficulty, he persuaded two consumptive patients to live. That was the beginning of the demonstration in this country of the fresh-air treatment of tuberculosis which Brehmer and others had introduced on the other side of the water. Since that day there has been a steady increase in the weight of evidence indicating that fresh air is one of the most valuable hygienic agents which may be utilized for the prolongation of human life and the strengthening of human vitality.

The analysis of the factors which are operative in producing such effects of the atmosphere upon human health and comfort has proved to be a much more difficult task than the recognition of these effects themselves. Yet we must pass next to a consideration of this problem—to exactly what factors and conditions should the evil effects of bad air and the beneficial effects of good air be attributed?

Older Chemical Theories of Ventilation

There are in general five different changes which take place in the air of an unventilated room as a result of human occupancy. Exactly

the same effects are produced by gas flames or other processes of combustion since the vital process is itself essentially a combustion, entirely analogous to the burning of organic substances outside the body. Leaving out of consideration for the moment the special types of atmospheric pollution contributed by various industrial processes, these changes associated with deficient ventilation are as follows:

1. The oxygen content of the air is reduced. A man of average weight, at rest, consumes about 764 grams, or 534 liters of oxygen in twenty-four hours.

2. The carbon dioxide content of the air is increased. Under average conditions of rest the amount of carbon dioxide produced will be about 840 grams or 427 liters, in twenty-four hours.

3. There is given off into the air a variable amount of partially oxidized organic matter. Much of this material is of nitrogenous nature such as the urea discharged in the perspiration. It is the substances of this sort combined with aromatic fatty compounds, chiefly derived from the skin and clothing, often partly from decomposition in uncared-for mouths, which we perceive as the "body odor" when we enter an unventilated room from the

fresh outer air and which is almost always to be noticed in a gymnasium.

4. The temperature of the air is raised by the heat liberated in the course of the body oxidations. In the average case considered above this heat would amount to about 2500 calories in twenty-four hours.

5. The humidity of the air is increased by the moisture given off in the breath and from the skin. We may place the average amount of moisture thus contributed at about 1400 grams in twenty-four hours.

It should be noted that all of these effects will be greatly increased with the increase of vital activity which accompanies physical exercise. The figures given above will be doubled by moderately active physical work and may be trebled or even quadrupled under very extreme conditions of exertion. The output of heat and moisture will also vary within wide limits in relation to the temperature, humidity, and amount of circulation in the surrounding atmosphere.

Considering the possible physiological influences of these various changes in the atmosphere of a badly ventilated room, it has been pointed out in Chapter I that the changes in oxygen and carbon dioxide content in the

worst ventilated room are far below the threshold of harmful physiological influence and may be dismissed from consideration as factors in the production of the harmful effects of deficient ventilation.

The third factor, the presence of partially oxidized nitrogenous compounds, is the factor to which the influence of bad air was chiefly attributed for the half century which followed the work of Pettenkofer. The theory of "crowd poison," "morbific matter," "anthropotoxin," was in harmony with the general view that disease was caused by organic miasms of decomposition, a theory so widely held fifty years ago. It received what at first appeared to be direct experimental confirmation from the work of various physiologists, particularly Brown-Séquard, who became the great apostle of this theory in the decade between 1880 and 1890. Working with d'Arsonval, he reported results which at first sight seemed highly convincing. In one series of experiments the expired air was collected by means of a special mask and the liquid condensed from this air was injected into animals, which promptly died with symptoms characteristic of ptomaine poisoning. An even more striking demonstration was effected by

placing animals in a series of cages and aspirating air through the series in such a way that each animal received the air vitiated by its predecessors. The animals at the end of the chain successively succumbed leaving the first one or two only alive at the end of an experiment; but if a trap of sulphuric acid (which was supposed to absorb the organic poison) were placed between the penultimate and the ultimate cage the last animal survived.

Almost at once, however, the results of Brown-Séquard were challenged by other experimenters who reported diametrically opposite results. A dozen or more investigations in England, France, Germany, Italy, and the United States proved beyond any reasonable question that the alleged evidence of organic poisons in breathed air could not be substantiated. It seems probable that the animals injected by Brown-Séquard and d'Arsonval died from the shock of the large volume of cold liquid introduced, from infection or from anaphylaxis, and that the animals in the respiration-chain died from asphyxiation. How the sulphuric acid protected the last animal is not clear, but it appears very possible that the extra resistance caused a leakage of air into the final chamber.

In a similar fashion results reported by Weichardt and by Rosenau in 1911, which were supposed for a time to be in harmony with the organic poison theory, were either disproved or explained on other grounds. It has been made quite clear by the work of the past twenty-five years that there are, in fact, no subtle organic poisons in the air of the ordinary badly ventilated room. The organic emanations in the air of such a room (body odors) may, as pointed out in Chapter I, when they are highly concentrated, exert a depressing psychological effect which decreases appetite and the inclination to physical work; but they are not the causes of the more serious and important effects which are observed under such conditions.

The Modern Thermal Conception of Ventilation

If changes in oxygen, carbon dioxide, and organic effluvia are not the primary factors in producing the harmful effects of bad ventilation, we must turn to the last two of the changes produced—the increase in temperature and humidity, for an explanation of the phenomena which are actually observed.

It was Hermans of Amsterdam who, in 1883,

first clearly enunciated the view that the evil effects of bad ventilation were primarily due to overheating and consequent interference with the elimination of heat from the surfaces of the body. This view was accepted by certain German engineers (Rietschel, Krieger, Mehl) and, in part, by Billings, Mitchell, and Bergey in this country. These authors in 1895 state that "The discomfort produced by crowded ill-ventilated rooms in persons not accustomed to them is not due to the excess of carbonic acid, nor to bacteria, nor in most cases to dusts of any kind. The two great causes of such discomfort, though not the only ones, are excessive temperature and unpleasant odors. Such rooms as those referred to are generally overheated, the bodies of the occupants, and, at night, the usual means of illumination, contributing to this result."

It was Flügge and his associates at Breslau who, in 1905, finally placed this theory on a firm experimental basis; and this German work has since been fully and completely confirmed by Hill and Haldane in England and by Benedict and the New York State Commission on Ventilation in this country. In one form or another these investigators have repeated a single crucial experiment which may

be schematically described as follows. A group of subjects is placed in a closed experimental chamber and kept there while oxygen decreases and carbon dioxide, organic matter, temperature, and humidity increase. They manifest the usual symptoms characteristic of "vitiated" air—headache, general discomfort, lassitude, changes in blood pressure, pulse rate, and the like. The attempt is then made to relieve these symptoms in two alternative ways—by permitting the subjects to breathe chemically pure air (admitted for example through a tube from outside) or by lowering the effective temperature of the chamber by cooling coils or the operation of fans, without altering its chemical composition. The first procedure is ineffective, the second completely effective.

In the Breslau experiments, normal individuals were placed in a cabinet of 3 cubic meters capacity and shut in for periods as long as four hours, the percentage of carbon dioxide rising as high as 1.0 to 1.5 per cent. No discomfort was experienced and the chemical impurity of the air had no influence on the power to carry out either physical or mental work so long as temperature and humidity were kept down. Paul shut a man in the chamber for

four and three-quarter hours and raised the temperature to 75° F., the humidity to 89 per cent of saturation, and the carbon dioxide to 1.2 per cent. The man became very uncomfortable. People outside breathing the air through a mouthpiece felt no discomfort, yet one of them became immediately uncomfortable upon entering the chamber. In another experiment, conditions inside were somewhat similar to those described above, the temperature being 86° F. the relative humidity 87 per cent, and the carbon dioxide 1.1 per cent. The subject was permitted to breathe pure outside air while in the chamber but was not relieved, while all symptoms were abolished by cooling the chamber to 62.6° F. (although the percentage of carbon dioxide had meanwhile risen to 1.6 per cent) or by the cooling effect of circulating fans.

One of the experiments conducted by Leonard Hill in England was described as follows:

> The experimental chamber, in this case, held approximately 3 cubic meters of air. In one class of experiments we shut within the chamber seven or eight students for about half an hour and observed the effect of the confined atmosphere upon them. We kept them therein until the carbon dioxide reached 3 to 4 per cent

and the oxygen had fallen to from 17 to 16 per cent. The wet-bulb temperature rose meanwhile to about 80° to 85° F. and the dry-bulb a degree or two higher. The students went on chatting and laughing, but by and by as the temperature rose they ceased to talk and their faces became flushed and moist. We watched them trying to light a cigarette (to relieve the monotony of the experiment) and puzzled by their matches going out, borrowing others, only in vain. They had not sensed the percentage of the diminution of oxygen, which fell below 17. Their breathing was slightly deepened by the high percentage of carbon dioxide, but no headache occurred in any of them from the short exposure to from 3 to 4 per cent carbon dioxide. Their discomfort was relieved to an astonishing extent by putting on the electric fans placed on the roof. Whilst the air was kept stirred the students were not affected by the oppressive atmosphere. They begged for the fans to be put on when they were cut off. The same old stale air containing 3 to 4 per cent carbon dioxide and 16 to 17 per cent oxygen was whirled, but the movement of the air gave complete relief.

Five years after Flügge's epoch-making reports, the weight of evidence, in view of the new view of ventilation, was almost overwhelming; and the report of the British Departmental Committee on Humidity and Ventilation in Cotton Weaving Sheds, presented in 1909, marked its complete acceptance by at least one important official body. In testify-

ing before this committee, Hill stated that "The ill effects of crowded rooms are due to the heat and humidity, and nervous fatigue from excessive illumination and excitement, not to the increase of carbonic acid. I think it is very doubtful if the unpleasant-smelling exhalations of the bodies of men, which become evident in close atmospheres, have any ill effect on men accustomed to them, and not of aesthetic temperament." Pembrey concludes that "Too much stress has been laid upon the question of carbon dioxide; its presence has been used as a test for defective ventilation, and in this way the mistake has arisen of considering it the injurious factor. All recent investigations, in this country, on the continent and in America show that temperature, moisture, and wind are the most important factors in connection with the injurious effects of badly ventilated rooms." Haldane and Boycott expressed essentially similar opinions; and Pembrey and Collis reported significant experiments on the quickening of the pulse and the increase of skin and body temperature in overheated workrooms. The committee as a result recommended a substantial relaxation of existing legal standards of carbon dioxide concentration and a strict limitation of the

wet-bulb temperature in the humid weaving sheds of the textile industry.

It is clear, then, that the effects of the atmosphere of an ill-ventilated room are primarily and fundamentally due to a high temperature (combined with stagnation and sometimes with high humidity) and consequent interference with the processes of body temperature regulation. The average human body, as we have seen, produces by its vital activities from 100 to 400 calories of heat per hour, depending upon the extent of physical exertion. This heat is given off to the surrounding air at a rate which would normally vary very widely with the temperature of the atmosphere. Yet by one of the most complex regulative mechanisms of the human body these processes are so beautifully balanced that the actual body temperature does not vary in health more than a degree on either side of the normal (98.6° F.).

At low temperatures this regulation is in part, but only in small part, accomplished by an increase in heat production; at high atmospheric temperatures there is no such adaptation, the heat production within the body being actually increased. It is, then, the rate of heat loss which varies and which is the chief

factor in maintaining the body temperature at a fixed level. When we are in a hot room, the tiny blood vessels of the skin expand (the face becomes flushed as we say) and bring a large amount of blood to the surface of the body to be cooled off. When we pass into cold outside air, the skin blood vessels contract, the blood is sent into the inner organs and the cooling effect of the air upon it is thus correspondingly reduced.[1] This is the chief regulatory process which operates at atmospheric temperatures below 50 degrees. As the temperature of the air rises, a new factor comes in, the increased production of sweat, which is evaporated (if the air be not too humid) with the absorption of heat which always accompanies the change of a liquid to gaseous form.

The primary effect of high atmospheric temperature is, then, to dilate the tiny blood vessels of the skin and to concentrate the blood flow in them at the expense of the inner parts of the body. In part, the feeling of discomfort and lassitude experienced is probably due directly to anemia of the brain and other internal organs consequent on this pooling of the

[1] After long exposure to cold a secondary reaction occurs which produces a dilation of the skin blood vessels in the exposed parts (the rosy cheeks of a person who has been out in nipping air). This serves as a protection of the part in question against freezing.

blood in the capillaries. Furthermore, as will be pointed out below, habitual exposure to such conditions leads to a lowered tone of the whole heat-regulating circulatory mechanism and an inability to respond to the demands which may be put on it, and in this way exerts a profound and important influence upon susceptibility to respiratory infections.

Direct Physiological Reactions to Overheated Air

It is a somewhat unfortunate fact that the modern conceptions of ventilation are less easy to present to the general public in dramatic form than were the older chemical theories. It was easy to descant upon the dangers of carbon dioxide or morbific matter and to arouse a wholesome respect for these supposed subtle and mysterious poisons. If, on the other hand, we recognize that it is merely overheating with which we have to deal, the matter may seem to the uninitiated to be one of relatively slight importance. Yet the investigations of recent years have made it abundantly clear that even a relatively slight excess of atmospheric temperature does, in fact, constitute a problem of the most serious moment. We may illustrate the nature of the evidence at hand by a brief

consideration of the results obtained in regard to this point by the New York State Commission on Ventilation.

The laboratory studies of the commission were conducted in two rooms especially equipped for the purpose at the College of the City of New York. One of these rooms, the Observation Room, was carefully insulated to prevent as far as possible heat loss and exchange of gases through the walls. Heating and cooling coils were located within the room and an elaborate system of ventilation made it possible to supply fresh air of any desired quality and in any desired quantity or to recirculate the vitiated air of the room itself. The second chamber, the Apparatus Room, contained the fans, heaters, and other appliances necessary to control the atmosphere of the Observation Room, with various automatic recording devices by which the conditions of the atmosphere were constantly recorded. Through a communicating window the subjects in the Observation Room could be observed while the heartless experimenter manipulated valves and levers, so as to expose them to this or that atmospheric condition, while their physiological reactions and mental and physical efficiency were constantly being

studied by physiologists and psychologists within the Observation Room itself.

Studies in this experimental suite at the City College were conducted almost continuously from December, 1913, to January, 1916. As a rule a squad of four subjects was used as a working unit and each experiment was continued for a sufficient number of weeks to yield significant results. Altogether 113 different persons were subject to observation.

The chief atmospheric conditions which were intensively studied during the course of this investigation were three in number: 68° F. with 50 per cent relative humidity; 75° F. with 50 per cent relative humidity; and 86° F. with 80 per cent relative humidity. The results obtained under such conditions of slight and moderate overheating may be readily summarized, so far as physiological reactions are concerned, as follows:

In the first place the temperature of the body itself is slightly but definitely increased by a rise in atmospheric temperature. During the summer months the average rectal body temperature at 8 A.M. was found to vary day by day directly with the average outdoor temperature during the preceding night. The average body temperature of the subjects fell

0.8° F. when exposed in the chamber to the 68° condition; it fell 0.1° when exposed to the 75° condition; and it rose 0.2° when exposed to the 86° condition. The average final rectal body temperature averaged 98.1° at 68°; 98.5° at 75°; and 99.3° at 86°.

The heart rate decreased markedly at 68° but remained high at 75° and 86°. The average final heart rates in the reclining position were 66 at 68°, 81 at 75° and 74 at 86°; in the standing position, 77 at 68°, 105 at 75°, and 99 at 86°. (It is not certain whether the higher heart rate at 75° as compared with 86° is significant or not.)

The most marked effect was that recorded by the Crampton Index, an arbitrary measure of the general efficiency of the circulatory system, derived from a comparison of blood pressure and pulse rate in the reclining and standing position. A high Crampton index means that on standing up after lying down the circulatory system is able to increase the blood pressure so as to meet the greater burden placed upon the system by erect posture without any marked increase in heart rate. A low index means that on assuming an erect position the heart beats much faster and that even then the blood pressure falls. It is a measure,

in other words, of the efficiency with which the circulation responds to a demand upon its power of adjustment. At 86° the general average Crampton Index was 60; at 75° it was 45; and at 86° it was 34.

Finally, the rate of respiration was slightly but distinctly increased, from an average of 17.9 at 68° to 19.3 at 75° and 19.7 at 86°.

Most important and significant results in regard to the effects of more extreme overheating have been obtained in a remarkable series of investigations which have been carried on at the Research Laboratory maintained at Pittsburgh by the United States Bureau of Mines, the United States Public Health Service, and the American Society of Heating and Ventilating Engineers for the past three years, and which are still in progress.[2] McConnell, Houghton, Yagloglou, and the other workers at this station have equipped a carefully controlled experimental chamber in which they have placed subjects, variously clothed, under a very wide range of temperatures, humidities, and degrees of air movement and have prolonged exposure to high

[2] See *Journal of the American Society of Heating and Ventilating Engineers*, 1922 to date.

temperature to the point at which a longer stay appeared definitely dangerous. Restlessness, irritability, headache, and palpitation of the heart, soreness of the eyes, a sensation of oppression on the chest, dizziness, and confusion were the chief symptoms experienced; and weakness and a dragged-out feeling persisted for some time after such experiments had closed. The extreme dry-bulb temperature which could be endured was 157° F. (wet-bulb temperature 100°, relative humidity, 15 per cent) for forty-five minutes while the extreme wet-bulb temperature [3] was 112.5° F. for thirty-five minutes. The body temperature under such conditions rose several degrees. The pulse rate seemed to be the best measure of discomfort, 135 beats per minute corresponding to marked discomfort and conditions becoming almost unbearable when the pulse rate exceeded 150 beats. With moderate overheating, both systolic and diastolic blood pressures fall; under more extreme conditions systolic blood pressure increases while the diastolic pressure continues to decrease and frequently becomes a negative quantity. Curiously enough, the increase in respiration rate observed by the New York State Commis-

[3] For explanation of this term, see page 69.

sion and by Vernon in England was not noted at Pittsburgh. Marked rise in body temperature and pulse rate were, however, apparent above 90° in saturated air. One of the most important contributions of these investigators is the recent report that basal metabolism (the rate of oxidation within the body) decreases with increasing temperature up to about 79° (with 100 per cent relative humidity) and then increases, the rise becoming very rapid when the atmospheric temperature is higher than that of the body. Such a temperature of 79° with 100 per cent relative humidity (corresponding in its physiological effects to about 88° with 50 per cent relative humidity in still air or 94° with 20 per cent relative humidity in still air) is clearly a critical temperature beyond which serious harmful results may be expected. Ideal conditions were found to lie between 62° and 69°.

These results obtained under laboratory conditions are fully confirmed by practical experience, such as was presented in testimony before the British Departmental Committee on Humidity in Cotton Weaving Sheds. Experts testified in this inquiry that the workers in mines subjected to a high wet-bulb temperature exhibit a marked degree of lassitude and

exhaustion. According to Professor Cadman, exertion begins to be accompanied with depression from a wet-bulb temperature of about 77° F. At 82° F. wet bulb "if clothes be removed and maximum body surface exposed work can be done providing a current of air is available." At 85° F. "only light work is possible," and at 95° F. work becomes out of the question (all wet-bulb temperatures).

Haldane, in the same inquiry, says that soldiers marching in uniform are liable to heat-stroke even at wet-bulb temperatures of under 70°; that at 88° wet bulb a marked rise of body temperature is noted with muscular exercise, and hard and continuous work is impracticable even when the subject is stripped to the waist; while at 88° to 90° wet bulb "in fairly still air the body temperature begins to rise, even in the case of persons stripped to the waist and doing no work; and when once started this rise continues until symptoms of heat stroke arise, unless the person leaves the warm air."

The ultimate effects of overheating, when carried to its physiological limit, have been well described by Charles N. Fiske, Surgeon in the United States Navy. Temperatures in the furnace rooms of naval vessels in the Tropics in early days sometimes passed 149°

F. dry-bulb and in one case reached 205°, with a high humidity. In 1909 and 1910 the attack rate for heat-stroke in the Navy was about 8 per 1000 and between 1861 and 1911 there were twenty deaths and thirty-three men invalided from this cause. Severe cramps and muscle twitchings attributed to local drying-out of the tissues and accumulation of waste products of metabolism are among the pronounced symptoms of heat stroke and the body temperature regulation may be completely upset so that a fever temperature of 104° to 117° is recorded.

The Influence of Overheated Air upon Efficiency

A second method of measuring the harmful effects of an overheated atmosphere is by a study of the work performed under the influence of various atmospheric conditions. So far as the effect of a slight degree of overheating is concerned, the New York State Commission studies again give us valuable data on this point.

In studying the three fundamental conditions to which reference has been made above (68° with 50 per cent relative humidity, 75° with 50 per cent relative humidity, 86° with

80 per cent relative humidity) the commission found that the performance of mental work was affected very little, if at all, by temperature variations within the limits in question. There was a suggestion that purely intellectual activity, such as mental multiplication, was performed a trifle better at 75° than at 68° and typewriting (involving a certain amount of muscular activity) slightly less well.

Vigorous physical work, such as lifting dumb-bells and riding a stationary bicycle, was, on the other hand, very markedly influenced by an overheated atmosphere. In the first series of tests on this point the subjects were stimulated to maximum effort under the 68° and 86° conditions. Twenty-eight per cent less work was accomplished in the hot room. In a second series room temperatures of 68° and 75° were compared and the subjects were allowed to work or remain idle as they pleased but were paid a small bonus in proportion to the amount of work performed, thus simulating more closely the actual circumstances of everyday life. Under these conditions the amount of work accomplished was 15 per cent less at 75° than at 68°. The close relationship between overheating and fatigue was well illustrated by the fact that the greatest de-

crease in efficiency occurred in the afternoon period. The morning production fell off 12 per cent at 75° as compared with 68°; the afternoon production fell off 19 per cent. It seems difficult to overemphasize the practical importance of such results as this. In view of the overheating which we know to be so common in industrial establishments, it is evident that the productive capacity of the country could be increased to an astonishing degree by attention to the problem of ventilation.

McConnell and Yagloglou at Pittsburgh [4] have studied productive efficiency under more extreme conditions. Taking a temperature of 90° with 30 to 60 per cent relative humidity as a base line they found that production was cut in half by an increase in humidity to the saturation point and a rise in temperature of 2°; or by an increase to 110° with 60 per cent relative humidity or to 125° with 30 per cent relative humidity. Production was reduced to one-quarter at 100° with saturated air at 120° with 60 per cent relative humidity and at 135° with 30 per cent relative humidity.

In actual practise Vernon [5] has shown that

[4] *Journal of the American Society of Heating and Ventilating Engineers,* Jan., 1925.

[5] Vernon, H. M., *Industrial Fatigue and Efficiency,* London, 1921.

factory production varies quite regularly with the seasonal temperature and furthermore that this variation is relatively slight where a good system of ventilation is in force and relatively great where ventilation is least efficient; as indicated in the table below:

INFLUENCE OF VENTILATION ON SEASONAL VARIATIONS IN OUTPUT

TINPLATE MILLS (VERNON)

Factory	Artificial Ventilation	Relative output in Dec. & Jan.	Relative output in July & Aug.	Per cent Reduction in summer
A	Good	100.5	97.5	3.0
B	Moderately good	102.5	97.0	6.4
C	Moderate (or more)	105.5	94.5	10.4
D	None (but good natural)	104.5	93.0	11.0
E	None (poor natural)	108.0	93.5	13.4

More recently Weston[6] has found that in weaving sheds production begins to fall off and fatigue effects are manifest as soon as the temperature exceeds 75° with saturated air.

The Influence of Overheated Air Upon Respiratory Disease

Even more important than the direct physiological reactions to overheated air, or than the effect of such air upon productive efficiency, is its influence upon susceptibility to colds, pneumonia, and other diseases of the

[6] See *Third Annual Report of the Industrial Fatigue Research Board to Dec. 31, 1922.*

upper respiratory tract. The Roman Seneca, in *De Providentia* warns his readers that the man who screens himself from the cold wind by his glazed windows, whose feet are kept warm by wrapping them in folds of flannel, and who never sups but in his stove-heated chamber, is not without danger of illness on the slightest change of weather; and the increased liability to colds among those who habitually live in an overheated atmosphere has been empirically recognized ever since his time, and no doubt before it. The seasonal prevalence of the respiratory diseases, with their maximum in winter, when the greatest contrast is found between indoor and outdoor temperatures, is of course a point in favor of this view. Definite quantitative evidence in regard to the question is, however, of very recent date.

It was Leonard Hill in England who first gave us a clue to the mechanism by which overheating affects susceptibility to respiratory disease; and his conclusions have been confirmed and extended by the New York State Commission on Ventilation. It appears from these researches that in a hot room normal subjects usually show swelling, moisture, and redness of the nasal mucous membranes, while ex-

posure to cold produces the opposite effect. On the other hand, air currents or drafts striking directly upon the face at low temperatures, or sudden changes, from a warm to a cold atmosphere, frequently produce an abnormal condition in which the mucous membranes become pale (from contraction of the blood vessels) while there is an increase, rather than a decrease, in swelling. Such a reaction produces a moist and distended but anemic condition highly favorable to bacterial invasion and may be interpreted as a failure of a normal defensive mechanism under extreme conditions. Hill believes that such a condition predisposes to disease for the reason that the defensive mechanism of the blood, the immunizing properties of the plasma, the cleansing action of the cilia, and the phagocytic action of the white blood cells are all diminished by the cold, while the pathogenic bacteria find a suitable nidus for their growth in the secretion of the swollen mucous membranes.

The New York State Commission found that industrial workers habitually exposed to high atmospheric temperatures (boiler-makers, furnace-men, etc.) and in still greater degree those habitually exposed to high temperature

combined with high humidity (laundry-workers) showed marked chronic disease of the nasal passages (atrophic rhinitis). Twenty-one out of 32 laundry workers showed this condition as against 9 out of 26 workers exposed to dry heat, 5 out of 27 outdoor workers and 2 out of 58 college students. Most important of all, when these workers who had been habitually exposed to overheated air, were tested out in the experimental chamber at the City College, it appeared that their nasal mucous membranes reacted quite differently to those of normal subjects. Even under the effect of relatively slight coolness they failed (as did the normal subjects under more extreme conditions) to show the protective reaction of diminished swelling and secretion which should accompany a contraction of the blood vessels of the mucous membrane.

Such abnormal reactions in the nasal mucous membranes produced by over-heating are too frequent and definite to be disregarded, as forming at least one important predisposing factor in promoting bacterial invasion of the upper respiratory tract. It is probable, however, that after active infection has actually begun there are still other harmful influences of overheated air which tend to hamper the

subsequent struggle of the cells of the body with the invading organisms. Thus, in the New York studies it was found that the formation of immune substances (hemolysins and agglutinins) by rabbits under experimental conditions was quite definitely delayed when the animals were kept at a temperature of 86° as compared with 68°. These results are in general accord with those obtained by previous workers who have studied the effect of moderately high temperatures upon the progress of infection in animals; although still higher temperatures (91° to 106° F.) exert a favorable influence upon recovery from infection. In the latter case the critical point for basal metabolism (to which we have referred in discussing the Pittsburgh studies) has no doubt been passed and a state of artificial fever created.[7]

Even more significant than such laboratory experiments was a large-scale practical study carried out by the New York State Commission on Ventilation which is so important as to require discussion in some detail. This par-

[7] Recent results reported by McDowell (*Journal of Hygiene*, Vol. III, p. 521) indicate that the resistance of rats to an intraperitoneal injection of pneumococci is decreased by transfer from a medium to a warm temperature immediately after injection; but that exposure for two weeks to a warm atmosphere (83° F.) increases their resistance to subsequent infection.

ticular investigation was primarily designed to test the effect, upon the prevalence of respiratory disease among school children, of three different methods of ventilation, which will be described in detail in a succeeding chapter. The practical difference in the actual atmospheric conditions maintained, however, was a difference in temperature. During the year 1915-16 this study covered 2500 children distributed in 58 classrooms in eight schools; during 1916-17, 3000 pupils in 76 classrooms in twelve schools. The health of the children was closely followed for eight weeks during the first season and for twelve weeks during the second season by nurses assigned for the purpose by the City Department of Health.

The classrooms were divided into three groups: (a) rooms ventilated by window inlets and gravity exhaust and kept at a mean temperature of 59° F.; (b) rooms ventilated by window inlets and gravity exhaust and kept at a mean temperature of 66.5° F.; (c) rooms ventilated by fan supply and gravity exhaust kept at a mean temperature of 68.5° F. Typical carbon dioxide records in three schools showed an average of 7.7 parts in rooms of type B and 5.9 parts in rooms of type C, corresponding (according to the more exhaustive

data from other series of experiments) to approximately 20 and 30 cubic feet of air supply per minute per pupil respectively. The fundamental difference between the three types of rooms was that in Type A we were using a low flow of cold air, in Type B a low flow of cool air, and in Type C a high flow of warm air. The overheating in the rooms of the last type was not extreme (mean 68.5° F.) and appeared to be entirely inseparable from the high air flow. With an air supply of 30 cubic feet per minute it is essential to maintain temperatures generally over 68° to avoid unpleasant drafts; while with a lower air supply temperatures can be kept well below that figure.

When the records for the two years were analyzed and averaged, it appeared that the amount of respiratory sickness in the 59° rooms and the 66.5° rooms was essentially the same; while the 68.5° rooms showed an 18 per cent excess of absence due to respiratory sickness and a 70 per cent excess of respiratory sickness among pupils in attendance. After a most careful study of social and economic conditions and of all other possible factors bearing on the case, there seemed no escape from the conclusion that even the slight de-

gree of overheating associated with an average temperature of 68.5° F. had exerted a very definitely harmful influence upon the susceptibility of the children to respiratory infections.

The Part Played by Relative Humidity in Determining the Suitability of Atmospheric Conditions

From the standpoint of the physiologist, the essential criterion of a given atmospheric condition is the net cooling effect which it exerts upon the human body. This effect will be conditioned by three factors—the temperature of the air, its relative humidity, and its movement.

The moisture of the atmosphere varies, as pointed out in Chapter I, within very wide limits. At any given temperature there is a certain maximum amount of water which the air can hold, any excess over this amount being condensed on dust particles in the form of fog or on adjacent surfaces (as the case of the fall of dew). We usually express the moisture content of the air in relation to this maximum amount which it could hold at the temperature which it actually possesses. Thus at 68° a cubic

foot of air can hold 7.5 grains of water; if there is actually 6.0 grains we say the air has a relative humidity of 80 per cent. Relative humidity is usually measured by a pair of thermometers, the bulb of one of which is enclosed in a closely fitting silk bag which is moistened just before a reading is made. When we observe such a pair of thermometers, the dry bulb will record the temperature of the air and the wet bulb will record a lower temperature (unless the air be saturated with moisture) on account of the fact that evaporation will take place from the moist silk and this evaporation will lower the temperature since the change of a liquid to a gas always absorb heat. From tables or charts the relative humidity corresponding to a given pair of wet- and dry-bulb readings can then be found. For example, a dry-bulb temperature of 70° with a wet-bulb temperature of 50° corresponds to about 20 per cent relative humidity; and a dry-bulb temperature of 70° with a wet-bulb temperature of 60° to about 55 per cent relative humidity; while, when both dry and wet bulbs are the same, the atmosphere is, of course, saturated.

The influence of atmosphere humidity upon heat loss from the body is quite different at

different temperatures. If the air temperature be low, there will be little or no discharge of perspiration and the body will lose heat chiefly by direct conduction to the surrounding air. Moisture in the air tends to produce a deposit of moisture on the clothing and moist clothing conducts heat more readily than dry clothing. Hence, very moist cold air seems chillier than dry cold air. This condition obtains up to a dry-bulb temperature of about 40° to 50° F. Above 50° the secretion of sweat begins and the cooling effect of the evaporation of this sweat becomes more and more important as a factor in heat loss, the higher the temperature. Under these conditions the cooling influence of conducting moisture is overbalanced by the fact that moisture in the air interferes with the evaporation of perspiration. Because of this interference with evaporation moist, warm air is far more uncomfortable than dry air at the same temperature. Air containing only 20 per cent relative humidity at 70° is about as comfortable (according to the Pittsburgh figures) as saturated air at 64°.

The combination of high temperature with high humidity is the most serious condition with which we have to deal in ventilation. It

was this condition which existed in the Black Hole of Calcutta and which is reproduced in less extreme form in certain industrial plants. Where such a condition must be met, every possible effort should be made to minimize its effects by special ventilation and short shifts for the workers.

Within the ordinary temperature range it would seem at first sight a matter of indifference whether we maintain a temperature of 70° with 20 per cent relative humidity or of 67° with 50 per cent relative humidity or of 64° with saturated air. It has been claimed, however, that there is another quite different factor at work—that dry air *per se* exerts a direct harmful influence upon the human body. It has been suggested that very dry air plays an important part in predisposing to respiratory disease, that it promotes abnormal conditions of adenoids and tonsils and that it is conducive to nervousness and general bodily discomfort.

In considering the influence of dryness, as in the case of temperature, we must take the factor of air movement into account. There has been much loose talk about schoolrooms "drier than the Desert of Sahara"; and it is true that the air of heated schoolrooms in cold

climates does often show as low a relative humidity as desert air. G. T. Palmer has recently shown, however, that the actual drying effect, as measured by the water evaporated from a porous cup under standard conditions, is much less in the schoolroom than in the desert on account of the relatively slight air movement.

Professor Ellsworth Huntington, in his remarkable study of the influences of climate and season, which will be discussed more fully in a later chapter, has demonstrated that the general death rate is at a minimum when the mean relative humidity outdoors is fairly high.

Such experimental results as are available in regard to the supposed harmful effect of dry air *per se* are, on the other hand, almost wholly negative. The New York State Commission on Ventilation devoted a considerable amount of time to researches along this line. Direct observations of the effect of various atmospheric conditions upon the nose and throat showed that hot moist air was worse than hot dry air, and this conclusion was borne out by the fact that laundrymen, exposed to hot, moist air showed a higher percentage of atrophic rhinitis than furnace men exposed to

hot, dry air. In regard to the question of nervousness induced by dry air, the commission undertook extensive investigations of the psychological reactions of experimental subjects and of the health and intellectual progress of school children exposed to air of varying degrees of dryness; but no effect of the dry air could be detected by the methods used. It should be noted that the variations in relative humidity studied were not very great, ranging only between 20 and 50 per cent of saturation in the cabinet experiments and between 29 and 42 per cent in the schoolrooms, for it is not practicable to humidify schoolroom air to any great extent in cold weather without producing frosting on windows.

In general it does not seem that there is at present any sound evidence which justifies the humidification of the air of the ordinary occupied room on physiological grounds. It has been claimed that the process is an economical one because it makes it possible to keep down the temperature. If any system of spray humidification is used, such as we find installed in certain schools, the cost of vaporization of the water will far overbalance any such savings. The ordinary pan on the radiator or in the furnace duct, common in

many houses, can, as a rule, exert only a psychological effect. It takes a considerable volume of water to influence the humidity of the atmosphere to any appreciable degree. Thus, to increase the relative humidity of the air in a room 20 feet long by 20 feet wide and 10 feet high from 40 per cent to 60 per cent relative humidity at 68° and with three changes of air per hour would require the evaporation of about one quart of water per hour!

The Factor of Air Movement

The third factor in determining the physiological effect of a given atmospheric condition is the extent to which conduction, or evaporation, or both, are favored by the movement of the air. In a still atmosphere the body is surrounded by a layer of air which has been rendered hot and moist by the heat and moisture given off and it is this hot moist air to which the surface of the body is actually exposed. Professor W. T. Sedgwick used to describe this zone as an "aerial blanket" wrapped about the body.

We can measure this factor of air movement by an ingenious device, first suggested by an English physician named Heberden one

hundred years ago, and later worked out by Leonard Hill, in the form of an instrument called the kata-thermometer. It is a specially constructed thermometer with a large bulb and a short stem graduated from 100° to 95°. In use it is placed in warm water till the liquid in the stem rises above 100° and we then observe the time in seconds which it takes to fall from 100° to 95°. This time necessary for the cooling of a hot body will necessarily be affected by air movement much as is the heat loss from the body and the use of this instrument has thrown much light upon the part played by air movement in determining the physiological influences of the atmosphere.

The Pittsburgh studies have indicated that in saturated air the following temperatures will produce approximately equivalent sensations of comfort; in still air, 67°; in air moving at 100 feet per minute, 69°; in air moving at 300 feet per minute, 73°; in air moving at 700 feet per minute, 75°.

The reader may perhaps have wondered, if overheating is so serious a factor, why we do not all die in summer. Some of the more sensitive of us do, as evidenced by the high infant mortality in the hot season. There are, however, three very good reasons why high summer

temperatures are not so harmful as much less extreme temperatures maintained indoors in winter. One of these reasons is that the air in summer, either outdoors or indoors with windows open, is almost always in active movement. In a series of observations made outdoors in New England summer weather I have found that temperatures at least as high as 75° F. are entirely comfortable and show excellent kata-thermometer readings. Similarly, a temperature up to 80° may be made satisfactory by the use of an electric fan. The cooling effect of air movement is, of course, enormously influenced by clothing. In the Pittsburgh studies air movement produced astonishing results in rendering high temperatures bearable for men unclothed above the waist.

In the second place, the effects of summer temperature are greatly minimized by the factor of acclimatization. We are all familiar with the lassitude which overcomes us on the first warm days of spring; but, as the season proceeds, the circulatory system gradually adjusts itself so as to cope more and more successfully with high atmospheric temperature. Vernon has studied this problem experimentally and finds that during one month of

experimentation the endurable limit of wet-bulb temperature for his subjects was increased from 82.5° to 88.5° F. The subjects not only showed greater power of endurance but the effect of a given temperature upon their pulse rate and respiration was markedly diminished.

Finally, and most important of all, the gravest effects, those on susceptibility to respiratory disease, are naturally not produced in summer because they depend upon the shock incident upon exposure to the chill outside air following upon the lowered circulatory tone due to a high indoor temperature.

Conclusion in Regard to What Constitutes Good Ventilation

We may summarize our discussion of the physiology of ventilation as follows: The chemical vitiation of the air of an occupied room (unless poisons or dusts from industrial processes or defective heating appliances are involved) is of relatively slight importance. The organic substances present, manifest as body odors, may exert a depressing effect upon inclination to work and upon appetite; therefore, occupied rooms should be free from body

odors which are obvious to anyone entering from without. (Such odors are never perceived by those who have been continuously in the room while they have been accumulating.) Objectionable effects of this sort have only been demonstrated, however, with a carbon dioxide content of over .2 per cent, which would correspond to an air change of less than 6 cubic feet per person per minute.

The harmful effects of the air of an ordinary badly ventilated room are due to interference with heat loss from the surfaces of the body. Such effects are very serious indeed. A temperature in excess of 68°, with little air movement and moderate humidity, exerts direct and important effects upon the circulation, causing particularly an increase in body temperature, a rise in heart rate and a fall in vaso-motor efficiency; it profoundly limits efficiency by causing a disinclination to physical exertion; and it markedly increases susceptibility to respiratory disease.

So far as general heat loss is concerned, any one of the conditions indicated below will produce approximately equal results, according to the experiments conducted by the Bureau of Mines at Pittsburgh, and any one of these conditions will be roughly equivalent, from the

standpoint of comfort to the condition found by the New York investigators to be best for the schoolroom.

SUMMARY OF ATMOSPHERIC CONDITIONS PRODUCING AN EQUAL COOLING EFFECT UPON THE CLOTHED BODY

DRY-BULB TEMPERATURES

Relative Humidity	Rate of Air Movement per Minute			
	None	100 feet	300 feet	700 feet
20 per cent	68.5	70.5	74.0	77.0
50 per cent	66.5	68.5	72.5	75.5
100 per cent	63.0	65.5	69.5	73.0

From the experience of the New York State Commission on Ventilation, however, it appears that high temperatures combined with high air velocities are actually less desirable than lower temperatures combined with lower velocities, so far as indoor conditions during the winter months are concerned. This is probably because the higher temperature necessary to protect the exposed face is harmful to the general tone of the blood vessels of the clothed parts of the body. The New York studies indicate that a temperature of 66° to 67° with about 50 per cent relative humidity and without too much air movement is the ideal one for schoolroom or office ventilation while a still lower figure should be set for work places where vigorous physical work is in

progress.[8] The air should be in gentle, but not excessive motion, and it is desirable that its temperature should fluctuate slightly from moment to moment. A moderate degree of variation in air movement and temperature keeps the body cool without chilling it and exerts a pleasantly stimulating effect upon the skin which is lacking either in stagnant air or in a steady warm current. The ordinary variations in humidity, which occur in the indoor air of a climate such as that of New England, are not of notable importance and artificial control of humidity under such conditions is of doubtful necessity.

[8] For invalids and particularly for the aged, whose power of heat production has become restricted, considerably higher temperatures must be maintained.

CHAPTER III

HOW TO SECURE GOOD VENTILATION

Heating and Ventilation

THE fundamental step in securing good atmospheric conditions is a systematic observation of the temperature. When a regulation was passed in New York City requiring that a large thermometer, with a heavy red line opposite 68°, be placed in a prominent place standing up from the front of every teacher's desk, the effect in controlling overheating was phenomenal. No schoolroom, no factory workroom, no office, no living-room should be considered as furnished, and fit for human occupancy, without a thermometer. Furthermore, a thermometer is of no value without someone to read it; therefore, it should be the definite duty of someone—the foreman in the shop, the teacher or a designated pupil in the classroom—to note the temperature at definite intervals. The regular reading of the thermometer is the first essential in the control

of air conditions; and whenever the temperature exceeds 68°, something should be done to remedy the condition.

Where an unduly high temperature exists, the first thing we look to in considering its cause is the question of artificial heat sources. It is very frequently the case that overheating is due, not at all to lack of ventilation, but merely to the fact that radiators or registers are pouring too much heat into the room. Anyone who has an opportunity to study a wide variety of ventilation problems will recall numerous factory workrooms, for example, in which the radiation is turned on full force in October and left turned on till May, with no reference whatever to atmospheric conditions. It is obviously impossible, therefore, to consider ventilation intelligently without considering heating as well, since the main object of ventilation is to avoid overheating. There are three methods of heating rooms which are in common use: (1) direct heating, effected by radiators or other heat sources within the room itself; (2) indirect heating, effected by supplying, to the room, air which has been previously heated elsewhere as by a furnace or a plenum-ventilation plant; (3) direct-indirect heating, a combination of the

other two, in which part of the heat of the room is supplied by warm air entering it and part by local radiators.

Either direct or indirect systems of heating can be controlled by automatic thermostats. These are devices in which the differential expansion of two suitable metals controls radiator valves or dampers in the air ducts. When in good working order, such thermostatic systems are highly efficient. In a certain mechanically ventilated school in New York City, for example, where the thermostats were carefully adjusted, 143 different observations of the room air showed 124 records between 64° and 69°, with 3 below 64° and only 3 above 71°. On the other hand, it must be recognized that thermostatic systems very easily get out of order. When the same school cited above was visited a few years later, its temperature control was found to have become so imperfect that the experiments contemplated had to be transferred to another building. In a New York office building, studied by the writer, 85 offices and workrooms had thermostatic and 147 hand control. There was somewhat greater overheating in the "automatically controlled" rooms than in the others. In one particular room the temperature for a

period of twenty-one days in February and March never fell as low as 70° during working hours, and was usually in the neighborhood of 80°. The reason was apparent when it was found that of 213 thermostats in this building, which were individually examined, 110, or 52 per cent, were out of order and not controlling their radiators.

It is obvious that even where automatic temperature apparatus is installed its operation must be checked up by thermometer readings; and where no such devices are provided, frequent attention must be given to radiators and registers in order to see that they are not doing their work too well.

Natural Ventilation

When a number of people are crowded together in a schoolroom or an office, a new problem arises, distinct from that of the control of artificial heat sources—the problem of getting rid of the heat produced by the vital processes of the body. We have seen that the average human being gives off about 100 calories of heat per hour. An occupied room will, therefore, become progressively warmer all the time (except in cold weather when heat

losses through walls and ceiling are considerable). The primary object of ventilation is to balance this bodily heat production by removing the heated air and replacing it by air which is cool, but not so cold as to produce objectionable and dangerous drafts.

Even in closed rooms the change of air produced by natural ventilation may be surprisingly large. Mäker and Schultze report that from 4 to 8 cubic feet of air per hour may pass through a square yard of sandstone, limestone, or brick with a temperature difference between inside and outside air of 9.5° F. The First British Departmental Report on Ventilation of Factories and Workshops (1903) gives some interesting data on this point, obtained by burning candles of known weight (yielding a known amount of carbon dioxide) and estimating the air change by the carbon dioxide content of the room air at the end of specified periods. In a large laboratory room with two double windows and one outside wall of sandstone, one inside wall of brick, one of sandstone, and one of wood and plaster, with a temperature difference between inside and outside air of 4° to 9° F., and almost no wind, the room air was completely changed every four or five hours. In rooms with fireplaces

the air was changed in one or two hours. With windows open the ventilation may, of course, be increased to almost any degree, depending on variations of temperature and wind pressure.

In dwelling houses, where there is no overcrowding, natural ventilation of this kind is generally sufficient for all practical purposes. The hospital ward, too, can, as a rule, be kept in good condition by ordinary window ventilation. The patients are, for the most part, in bed or, at least, warmly clad, and under control; overcrowding is not great, and intelligent supervision of windows is easily possible.

In the use of natural ventilation by means of windows, it is, however, essential to maintain more or less constant watchfulness and to make ample use of the somewhat uncommon attribute of common sense. Many people seem to think that if a single window be opened, either top or bottom, fresh air will come in; but this is by no means necessarily the case. Air does not move of its own volition. It moves as a result either of mechanical pressure or of temperature differences; and air will not enter a room unless a corresponding amount can find an exit at some other point. If a room be otherwise tightly closed,

therefore, the opening of a single window may lead to no air change at all. Or the opening of a window may provide an outlet instead of an inlet, as in the case of a hotel room with a transom over the door and a single open window. In such a room hot air from the corridor may flow in through the transom and out through the window all night without the least beneficial effect upon the atmosphere of the sleeping room; while closing the transom and opening the window top and bottom would quickly produce the desired result. What one must do in a given case is to give a moment's thought to temperature conditions and wind movement and provide an outlet for warm air above and an inlet for cool air below.

In schools, in crowded offices and workrooms and in auditoria, such natural ventilation by the use of windows alone is not likely to prove satisfactory. When the air outside is nearly as warm as that indoors, the temperature differences, unless a strong wind is blowing, will provide an altogether insufficient supply of air to remove either body odors or excess heat produced in a crowded room. In cold weather, on the other hand, insuperable difficulties arise as a result of inequalities of distribution. In a school or a factory where

there is a row of five or ten or twenty persons extending from a window across to the inner wall of the room, it is out of the question to ventilate by admitting the untempered air of winter. Either the temperature near the window will fall so low as to chill those in that vicinity or the temperature at the other side of the room will rise too high, the latter result being the more usual one.

Natural ventilation, then, will generally serve for the living room and for the hospital ward, but not, as a rule, and without certain modifications, for the school, office, factory, and auditorium. In such places special provision must be made for the removal of heated air and the supply of fresh cool air. There are two general methods of attaining this end: Gravity Ventilation and Fan Ventilation; but, before describing these processes in detail, it will be desirable to review for a moment the development of popular conceptions of good ventilation and the embodiment of these conceptions in legislative standards.

Standards of Ventilation

The system of gravity ventilation—in which inlet and outlet openings or ducts are provided

but reliance for the movement of the air is placed upon temperature differences or "chimney action"—was the one used by the pioneers of ventilation practice in the last century. Tredgold, who wrote a very influential book on ventilation in 1808, and Reid, who ventilated the House of Commons and published a work entitled *Illustrations of the Theory and Practice of Ventilation,* in 1844, practiced with much success in England along this line. Reid later took up his residence in America and in 1858 published a work on *The Ventilation in American Dwellings* in which the new idea of using "fanners" for mechanical ventilation is mentioned only once or twice.

During the last part of the nineteenth century great improvements were made in the construction of fans and other mechanical appliances used in forced ventilation and fans gradually began to supplant gravity processes, as a result of the belief that the essential object of ventilation was a rapid change of air for the purpose of diluting organic poisons.

It is primarily to the German hygienist, Max von Pettenkofer, that we owe the conception that a large volume of air flow is essential to good ventilation, as well as the idea of using the amount of carbon dioxide present as a

measure of the success attained and as a basis for arbitrary standards of adequacy. We have pointed out that in investigations conducted as early as 1862 Pettenkofer showed that neither lack of oxygen nor excess of carbon dioxide could in themselves account for the discomfort and injury to health experienced in badly ventilated rooms; but he believed these harmful effects were due to hypothetical organic emanations of a poisonous nature, arising from the human body. Since there was no way of directly estimating these "morbific" substances, he used carbon dioxide as an indirect measure of their concentration and thus inaugurated the carbon dioxide standard in ventilation. Under the influence of Parkes in England and of John Shaw Billings (whose widely influential book on ventilation was first published in 1884) in America the carbon dioxide standard was universally accepted; and it was very soon translated into a mechanical standard by the following line of reasoning.

The average individual produces approximately .6 cubic foot of carbon dioxide per hour in the process of respiration. Normal outdoor air contains .0003 part of carbon dioxide. If we assume that .0006 part of carbon dioxide represents an upper permissible

limit (more carbon dioxide than this being held to indicate a dangerous concentration of hypothetical body poison) it is easy to compute the amount of fresh air (containing .0003 part CO_2) which must be brought in per person per hour to prevent the concentration of CO_2 in the room air from rising above .0006 part. This we do by the formula

$$\frac{.6}{.0006-.0003} = x$$

which gives us 2000 cubic feet per hour, or, approximately, 30 cubic feet per minute.

This was the basis, and the sole basis, of the ventilation standards worked out by Pettenkofer, Parkes, and Billings[1] and used as a powerful argument for mechanical ventilation by Professor S. Homer Woodbridge during the last decade of the nineteenth century. Coming with the authority of the most eminent hygienists of the time, it was inevitable that the standard of 30 cubic feet per minute should have been accepted without question by the engineering profession. When the American Society of Heating and Ventilating Engineers was organized in 1895, this concept of ventila-

[1] It may be noted, however, that Billings himself still recommended gravity ventilation for schools.

tion was in its fullest vigor, and this society naturally lent its influence to the embodiment of the ideal of ample air flow in definite legal form so far as school buildings were concerned, setting in motion about 1900 an organized campaign with this end in view. The movement thus inaugurated has met with a success which was scarcely justified by the soundness of the underlying theoretical assumptions which were involved.

On the first of January, 1925, there were 17 states with no laws or statewide regulations covering school ventilation. There were 7 states with laws containing vague but pious aspirations to the effect that schools should be "adequately" or "properly" ventilated or so ventilated as to avoid the accumulation of products of respiration in harmful concentration. There were 24 states, however, with laws or regulations specifying definite standards for school ventilation, based on the Pettenkofer theory. In Indiana, Montana, New York, North Dakota, Oklahoma, Pennsylvania, South Dakota, Texas, and Virginia, there was a state law of this type. In Alabama, Illinois, Maine, Michigan, Minnesota, New Jersey, and Utah, there was a regulation to the same effect promulgated by the

state educational authorities: in Florida, Idaho, Louisiana, Vermont, and West Virginia by the State Health Department; in Ohio and Wisconsin by the State Industrial Commission; and in Massachusetts by the Department of Public Safety.

In all of these 24 states except Alabama, Ohio, Minnesota, and Wisconsin the standard which is set specifically calls for an air supply of 30 cubic feet per minute. In Ohio six changes of air per hour are required which, under ordinary conditions of occupancy, would amount to the same thing. In Alabama and Minnesota the figure set is four air changes per hour, which would require 10 to 15 cubic feet per minute per person. In Wisconsin the standard is 2 cubic feet per minute per square foot of floor area, which would generally amount to over 30 cubic feet per person per minute. This Wisconsin Code (drawn up by the Industrial Commission less than two years ago) is perhaps the most astoundingly reactionary set of regulations anywhere in force. It not only requires that "positive ventilation" be "provided and maintained," but specifically prohibits gravity direct-indirect systems, which, as we shall see, are the systems now considered most generally satisfactory for

the ventilation of the average schoolroom in the light of modern knowledge.

While this remarkable Wisconsin code seems to allow no exceptions, it should be noted that many of the regulations discussed above are not of universal application within the respective states. The Alabama rule, for example, applies only to rural schools; the New York law excludes first and second class cities, the Utah regulation applies only where mechanical or gravity ventilation is used; the West Virginia provision applies only to "artificial ventilation systems." On the other hand, the large cities have, in most instances, specific regulations of their own along the same lines. Professor J. R. McLure, in his admirable monograph on *The Ventilation of School Buildings,* has reviewed the actual practice of 96 cities in 31 states in regard to school ventilation. Out of seven hundred school buildings constructed in these cities during the past seven years (since January 1, 1918), 513 or 73 per cent were equipped with systems of mechanical ventilation. Fan supply and gravity exhaust was used in 47 per cent of the buildings, fan supply and fan exhaust in 24 per cent, windows alone in 16 per cent, and window supply with gravity exhaust in but 6 per

cent. McLure finds, however, that in a group of 25 cities where mechanical ventilating systems were installed, the systems were operated regularly during the season when artificial heat was used, in only 104 out of 205 buildings.

It would be safe to say that approximately one-half the schools built in the United States are today constructed under official regulations requiring the installation of systems of ventilation capable of supplying 30 cubic feet of air per minute for each child—which means, of course, systems of fan ventilation. Yet this whole complex legal and administrative structure rests upon the fundamentally erroneous conception that the object of ventilation is to dilute non-existent organic poisons.

The proper basis for estimating the adequacy of ventilation must be sought in a consideration of the problem of heat removal; and it is obvious that so far as heat removal is concerned external atmospheric conditions will affect it so materially as to make any rigid mechanical standards of air flow quite meaningless. Under certain conditions the standard of 30 cubic feet per minute may very well represent the true needs of the situation. According to a low estimate, an average adult gives off 400 British thermal units per hour.

Let us assume that this heat must be removed by air entering the room at 60° and leaving it at not above 70°. One British thermal unit raises the temperature of about 50 cubic feet of air by 1°, or the temperature of 5 cubic feet of air from 60° to 70°. Hence, our average adult producing 400 British thermal units will require 2000 cubic feet of air per hour at 60° to keep the surrounding temperature from rising above 70°. An ordinary gas burner produces 300 British thermal units per candlepower hour; therefore, each such burner requires 1500 cubic feet of air per candlepower. These calculations, of course, ignore direct heat loss through walls and ceiling which, with a zero temperature outside, may carry off the heat produced by 50 or 100 people. In an interior auditorium, however, it is clear that an air supply of at least 30 cubic feet per capita per minute will be urgently required. In many industrial processes in which the heat produced by human beings and illuminants is reenforced by the friction of machinery and the heat from solder pots, furnaces, mangles, pressing irons, or other similar sources the amount may have to be increased still further.

The fact is that while 30 cubic feet per

minute may be set as a rough standard sometimes desirable to attain in very large rooms with slight heat loss, it may be insufficient in certain cases and in many other cases is an unnecessarily high figure. Hygienists must insist on standards of air conditions actually maintained, rather than on any arbitrary mechanical standards assumed to be capable of maintaining them. Any system which does not guard against overheating is inadequate, however large a volume of air may be forced into the room, and a system may be entirely adequate which supplies 10 cubic feet of air per minute if the temperature be properly regulated.

The New York Studies on Window-Gravity Ventilation and Fan Ventilation in the Schoolroom

It is a consideration of such facts as these, accentuated by active dissatisfaction with the actual results of fan ventilation in schools, which has led, during the past ten years, to a revival of interest in the system of gravity ventilation. The main reason for the appointment of the New York State Commission on Ventilation and the support of its work by the Milbank Fund was the desire to

discover in the light of modern physiology whether widespread criticism of fan ventilation, as officially enforced by lawmaking bodies, was justified and whether gravity ventilation or some other procedure could be substituted for it with advantage, under any or all conditions. It will be profitable, therefore, to consider in some detail the investigations of the New York State Commission in regard to the practical ventilation of schoolrooms.

After preliminary investigations of six schools, at Springfield, Mass., in the spring of 1915, the commission began its systematic work in the fall of that year. Detailed studies were conducted during the school terms of 1915–16 in four schools in New York City and one at Fairfield, Conn.—the special types of ventilation observed in twelve different schoolrooms including window supply with no special exhaust, with gravity exhaust and with fan exhaust, and fan supply, with no special exhaust, with gravity exhaust, and with fan exhaust. The schoolrooms utilized in this study were selected as typical examples of the types of ventilation in question, and in some cases minor alterations in construction were made to render them entirely satisfactory for our purpose. Two of the rooms in one school

(51 Bronx) were equipped with an independent system of plenum and exhaust ventilation specially designed for the more elaborate experiments which we desired to conduct later in regard to air distribution, re-circulation, and the like. In the conduct of this particular project a period of one to two weeks of continuous intensive study was devoted to a particular room, our observers then passing to another room for a similar period. Temperature and humidity records were made at many points in the schoolroom, with kata-thermometer observations, anemometer measurements, and carbon dioxide determinations, and in addition to the physical and chemical results systematic expressions of opinion as to sensations of comfort were obtained from the teachers and from our own observers.

This intensive study was checked, during the same school year, by less detailed observations of 20 other rooms in School 51, Bronx. Our criteria of the conditions maintained were based on temperature and humidity records and carbon dioxide determinations and on exhaustive votes by the teachers and our own observers as to freshness of the air, temperature, dryness, breeziness, etc.

Another study, along similar lines, was

carried out in the following season between November, 1916, and March, 1917. The work was conducted in School 33, Bronx, and in Schools 97 and 115, Manhattan. In each of these schools three or four rooms were operated with the system of fan ventilation installed in the building, while we used for comparison three or four other rooms in each school in which the fresh air inlets had been blocked off and window deflectors provided so that window inlets could be used instead. In Schools 97 and 115 this primary study was supplemented by a more cursory examination of a considerable series of other rooms of the two types specified above (window inlet gravity exhaust, fan inlet gravity exhaust). Exhaustive studies were made as before in regard to temperature, humidity, air movement, and carbon dioxide supplemented by kata-thermometer records and comfortimeter records as a measure of deheating effects, by atmometer studies of drying effect, and by the use of a special air thermometer for recording minor fluctuations in temperature. Votes in regard to freshness, temperature, dryness, and other sensible qualities of the air were recorded by the observers of the commission, by teachers and by nurses; and in the two Manhattan schools careful

studies were made in regard to the occurrence of respiratory illness during the period of investigation.

The investigations described above appeared to indicate interesting differences in the sensation of comfort experienced in rooms ventilated by windows as compared with those equipped with plenum fans, and in order to exclude any subjective influences in the formation of judgments we conducted, in the autumn of 1916 and early winter of 1917, a special investigation at the Wadleigh High School, New York City, in regard to this point. Two rooms were equipped for window ventilation and compared with four fan-ventilated rooms of the usual type, and comfort votes were recorded under varying conditions by squads composed of twenty-four high-school girls who were blindfolded, led to the room, and asked to record their sensation in regard to odor, stuffiness, temperature, drafts, and general comfort on an arbitrary numerical scale without any knowledge as to what kind of ventilation was actually in use. Exhaustive observations of air conditions in regard to temperature, humidity, air flow, and deheating effect were also made during the course of the experiments.

In addition to these main lines of investigation, special studies were conducted in regard to the incidence of respiratory disease in schoolrooms ventilated by different methods, in regard to the mechanical problems of air distribution within the schoolroom, in regard to the value of humidification, and in regard to the process of recirculation. Reference to the results of these special studies will be made in succeeding paragraphs.

Our first extensive studies in 1915–16 indicated that window ventilation alone, did not, as a rule, yield satisfactory results. A schoolroom without gravity exhaust, with air entering at the windows, and with direct radiation may, in mild weather, be kept in a comfortable condition, liberal use being made of windows, doors, and transoms. With the onset of colder weather, it becomes necessary to cut down the area of these openings and it proves generally impossible to keep the interior of the room properly aired. If the windows are open only at top or bottom, there is no outlet for warm air. If they are open both top and bottom, we get a short circuit which chills those near the windows without relieving those in the interior of the room.

The presence of a gravity exhaust duct in

the inner wall of the room (window-gravity ventilation) completely alters the situation by opening a channel through which outgoing air can pass. It is possible, under this arrangement, for air currents to cross the room and in so doing partly push ahead of them and partly carry with them the used air of the room. The stagnation is thus appreciably relieved. Diffusion is aided, temperature becomes more evenly distributed, and if window boards and radiation below the windows is provided local drafts are lessened to a point which is quite unobjectionable.

The experiments of the commission indicated that in schoolroom ventilation the choice in practice seemed, in general, to lie between the use of fan supply and gravity exhaust and this new method of window supply and gravity exhaust. The former procedure (fan-gravity) furnishes a much more complete aeration, with uniformly low carbon dioxide values, and its deheating effect as measured by the katathermometer is high. On the other hand, the actual air temperature which must be maintained under this system must be slightly higher than that which proves satisfactory with the window-gravity method.

The less intensive study conducted on a lar-

ger group of rooms, with special attention to the details of various methods of window ventilation, fully confirmed these first results. Again, we noted a significantly lower temperature maintained in the window-ventilated rooms, as a result of the teachers' own free choice. It was within their power to have warmer rooms and yet they voluntarily chose temperatures averaging between 66.5° and 67.5° F. in preference to 68° or 69° F. It was made abundantly clear that schoolrooms provided with window deflectors, and with radiators located beneath the windows, and with exhaust ducts, may be successfully ventilated throughout the winter season without the use of fans and with the maintenance of agreeable conditions satisfactory to teachers and expert observers. The practical experience of members of the commission suggested, however, that proper dampering of the exhausts is desirable in such systems in order to avoid back drafts. In some cases the installation of exhaust fans or of heating coils in the exhaust duct may be desirable in order to maintain a positive exhaust, especially during the period of milder weather and when the wind pressure is slight or in an unfavorable direction; such fans should, however, be de-

signed to produce only a slight air flow or the special virtues of the window system may be lost.

The study conducted in three different schools during the winter of 1916–17 was the most extensive and carefully controlled of all the commission's investigations and makes it possible to draw reasonably clear conclusions as to the relative values of gravity and fan ventilation. In one of the three schools the radiators were equipped with defective thermostats and both gravity and fan-ventilated rooms were overheated; in the second school both types were cool and well-aerated; in the third the window-ventilated rooms were overheated and unsatisfactory while the fan rooms were in good condition. In general, this study again showed that window-ventilated rooms are likely to be less perfectly aerated and are likely to show a slightly lower and more variable temperature, combined of course with less air movement. The actual rate of heat loss, as measured by the kata-thermometer, is, however, greater in the fan rooms, the excess of air movement overbalancing the higher temperature.

Lower aeration and less air movement might, on generally accepted theories of ventilation,

be considered as disadvantageous; but against such a conclusion we must set the records of the actual sensations experienced. In the third school, where the window rooms were actually much more overheated and much less aerated than the fan rooms, this difference was correctly recorded by the votes of the teachers —to the disadvantage of the window rooms. In the other two schools, however, the analytical data indicate that both fan- and window-ventilated rooms possessed about the same physical and chemical characteristics (except that the former were very slightly warmer and more uniform in temperature and better aerated). Yet in both cases, the general consensus of the teachers' opinions strongly favored the window rooms which they reported as less stuffy and less draughty.

Finally, the commission, as noted above, conducted a special study at the Wadleigh High School, to test out more carefully the question of the preference which appeared to exist for slightly cooler window-gravity ventilated rooms as compared with slightly warmer fan-gravity ventilated rooms, to determine whether this preference was due to a real objective effect which would be felt by blindfolded subjects who did not know what the

method of ventilation was, and to elucidate, if possible, the reasons for any effect which was manifest. This investigation showed that the window rooms were, as a matter of fact, slightly, but distinctly, preferred by a group of high-school girls, who judged the question purely by their bodily sensations uninfluenced by prejudice or by varied stimulations, sight of open windows, personal associations, etc. The window rooms were criticized as too cool more often than the fan rooms; but fan rooms were more often pronounced malodorous and stuffy, too warm and yet too drafty.

The reason for this preference seems to be chiefly a thermal one. The window rooms were more comfortable because they were cooler, for even though there was little difference in temperature as measured 3 feet above the floor, yet below this level the window rooms were distinctly lower in temperature. The kata-thermometer indicated, however, that the fan rooms extracted more heat from the body and in this sense that they were more cooling than the window rooms. Inasmuch as the window rooms were preferred, it appears that coolness due to low temperature and relatively slight air movement is preferable to coolness produced by air motion in the presence of higher

temperature. There are several differences in the mode of heat loss from the body in the two types of rooms which may help to explain this difference in the sensations recorded. In the first place the window rooms show greater differences between the temperature at the floor and at the 3-foot level. It is conceivable, though not probable, that such a condition is agreeable. In the second place, heat loss in the window rooms by radiation and conduction is relatively greater, heat loss by convection relatively less. The nose and throat are thus bathed in cooler air and the rate of heat loss from the clothed body as compared with the unprotected face must be relatively greater. This may very probably be a condition favoring comfort. In the third place, the fact that the air movement in the case of the window rooms is more variable from moment to moment may be a factor which plays a part by producing a pleasant sensation of "breeze" without causing "drafts."

That a real superiority exists, however, appears quite certain.

In general, then, the studies of the New York State Commission indicated that for the average schoolroom which is to be maintained, not as an open-air room, but at a temperature

between 65° to 70° F. ventilation by windows alone, without the use of exhaust ducts, is generally likely to prove unsatisfactory. On the other hand, either a window-supply, gravity-exhaust system or a fan-supply, gravity-exhaust system may yield very satisfactory results as measured by ordinary analytical standards. The commission says, of these two procedures,

The first difference between these two methods of ventilation lies in the less complete aeration attained by window ventilation. Our results are uniform in indicating that the carbon dioxide values will be somewhat higher with window ventilation and this result is an expression of the fact that the air change provided by this method falls materially below the 30 cubic feet per minute which in the past has been accepted as essential. Furthermore, in fan ventilation the air passes across the top of the room and back along the floor in the opposite direction—while in window ventilation the direct air flow is across the top of the room from the center to the inner wall, with no strong current in the zone of occupancy. In view of the modern views of ventilation as primarily a procedure for maintaining desirable thermal conditions, the diminished aeration seems to be unobjectionable, and our results indicate that aeration diminished in this way to a reasonable degree and accompanied by little or no air flow near the floor is not accompanied by the production of offensive odors and is beneficial rather than harmful to the health and comfort of the occupants.

The second difference, correlated closely with the first, is to be found in the fact that window-ventilated rooms are characteristically maintained at a temperature slightly lower than fan-ventilated rooms. Considering the large number of schoolrooms considered in the course of our investigation, it seems reasonably clear that, in a window-ventilated room with a comparatively slight air movement, temperatures between 66° to 68° F. are borne with comfort; while in the fan-ventilated room with the increased heat loss due to greater air movement the temperature must be maintained between 68° and 70° F. Even under such conditions the rate of heat loss as measured by the kata-thermometer is greater in the fan-ventilated room, but our results indicate that the kata-thermometer somewhat exaggerates the effect of air movement upon the clothed body.

Finally it appears from our studies with specially designed air thermometers that the temperature in the window-ventilated room is characterized by continuous slight fluctuations as contrasted with a relative constancy of temperature maintained in the fan-ventilated room.

The choice between these two methods must in general, therefore, rest (1) upon the relative desirability of surrounding the body with a rapidly moving current of warmer air or a more moderate current of cooler air, and (2) upon the relative cost of construction and operation of systems of the two types.

In order that the window-supply, gravity-exhaust system may operate most successfully, it should include the following provisions, according to the conclusions of the commission:

(*a*) Radiators must be located beneath the windows and extend for the full width of the windows from which the air supply is to be derived. These radiators, because much larger than those customarily installed in ordinary plenum systems, should be either automatically controlled by intermediate acting thermostats or equipped with fractional or modulating hand-controlled valves, placed at the top of the supply end of the radiator. Even when automatic control is included it is best to supplement it by the provision of hand control as well; and standard metal radiator shields are desirable to protect the pupils nearest the radiators from excessive heat. It is to be noted that the use of intermediate acting thermostats or modulating hand-controlled valves presupposes the use of a vapor vacuum steam heating system.

(*b*) Deflecting boards of some satisfactory type should be placed at the bottom of the windows. Devices which include small box-like openings, and devices which involve the use of filtering screens of various types are undesirable. A plane glass deflector one foot high is fairly satisfactory, but the best results may be obtained by the use of curved vane deflectors which secure the most equable distribution of the air. The windows in the use of this method should open from the bottom and not from the top.

(*c*) In order to avoid certain practical difficulties it is recommended that windows should be so constructed as to open easily from the bottom, and that window shades should be firmly attached to the window frame, the best arrangement being that which includes two shades anchored midway between top and bottom, one

to be pulled upward and the other downward, these shades being so guided by cords and pulleys as to avoid the shaking of the screens by the incoming air flow.

(*d*) Exhaust ducts having a total area of not less than 8 square feet for an ordinary schoolroom should be provided on the wall opposite the windows.[1] These exhaust openings should be conveniently dampered so that their area may be adjusted to varying weather conditions. The exhaust ducts should be carried up through the interior of the building so as to avoid chilling and the tendency to back drafts should be further reduced by placing an aspirating cowl on the opening at the roof and perhaps by placing heating coils in the exhaust duct.

(*e*) The schoolroom should not be overcrowded. The successful results reported by the New York Committee with this method of ventilation have been obtained with a cubic space allowance of 250 cubic feet per 2d grade child (39 children in an ordinary schoolroom) and with a cubic space allowance of 310 cubic feet per 6th grade child (31 children in an ordinary schoolroom).

(*f*) A large thermometer with 68° F. clearly indicated as a danger point should be displayed in a prominent position on the teacher's desk.

The Relative Value of Gravity and Fan Methods of School Ventilation

It seems clear from these results of the New York State Commission studies that ventila-

[1] The author believes from his more recent experience that this standard of 8 square feet is perhaps unnecessarily high.

tion of the schoolroom by the window-supply gravity-exhaust method is on the whole more satisfactory than that attained by the fan system. Yet the construction of school buildings equipped with the window system of ventilation is restricted by law, as we have seen, in half the states of the union, since only a fan system, of course, can comply with the provision that a supply of 30 cubic feet of air per minute shall be ensured. The excellent results obtained in New York with window inlets were associated with an air flow of 20 cubic feet per person per minute or less (about .08 per cent CO_2) and the harmful effects of odors noted in the City College experiments only appeared with an air change of about 5 cubic feet (over .20 per cent of CO_2). In view of these facts, it seems pertinent to inquire into the extent of the economic burden imposed by such legislation. So far as construction costs are concerned, Professor J. R. McLure, in his admirable monograph on The Ventilation of School Buildings,[2] estimates that the additional cost of the ordinary mechanical system of ventilation as compared with the New York State Commission system of window supply

[2] Teachers College, Columbia University, Contributions to Education No. 157.

and gravity exhaust is between 1.22 and 1.55 cents per cubic foot of building contents. My friend, Professor G. D. Strayer, of Teachers College, has been good enough to estimate for me the total volume of new schoolhouse construction in the United States in an average year. He places the figure at 750 million cubic feet. Let us make the assumption (absurdly low in view of McLure's study) that only one third of this total group of buildings is equipped with mechanical ventilation; and we find that over three million dollars a year is needlessly spent on the thirty-cubic-feet-per-minute fetich.

This is by no means the whole story, since the systems of mechanical ventilation, after they are constructed, require the wasting of more millions, if we wish to operate them as designed. Here the problem will vary with each state, depending on the mean outdoor temperature; but we may take New York State as a typical single example. Setting aside the cost of operating the fans themselves (no inconsiderable item), the fan system with 30 cubic feet of air flow per minute, as compared with the gravity flow of 10 to 15 cubic feet, involves the raising of more than twice as much air from the outdoor temperature to that

of the air at the room outlet. The same number of heat units will be needed in either case to warm up the building and thereafter to balance heat loss through the walls. The excess heat which passes off with the air in the exhaust duct is just so much clear waste.

The average mean outdoor temperature for the months of November, December, January, and February in New York State is under 35° F. The temperature of the air in the exhaust duct (with either fan or gravity systems) was found by the New York State Commission to be at least 65°. The fan system, therefore, wastes on the average the heat necessary to warm 15 cubic feet of air 30° every minute and for every child. There are some 24,000 minutes of school sessions during the four coldest months so that the total excess air thus warmed amounts in one winter to 360,000 cubic feet per child. My colleague, Professor E. H. Lockwood, informs me that it costs about 60 cents to raise the temperature of one million cubic feet of air 30° so that we have a wastage of 20 cents per child for this purpose during each school year. If but one half of the two million school children of New York State are in fan-ventilated schoolrooms, there is a direct waste of $200,000 a year, in money burnt up

and poured into the circumambient atmosphere.

If this were all, if the harm done by mistaken theories of ventilation were limited to the pocket-book, the matter might be dismissed as one to be settled between public appropriating bodies and their own consciences. There is, however, a still more fundamental, and still more serious aspect of the case. Window-gravity ventilation is not only cheaper than fan-gravity ventilation; it is also better, so far as the average schoolroom is concerned. We have already seen that the window-inlet classroom slightly below 67° is distinctly more comfortable than the fan-ventilated classroom which must be kept slightly above 68°. There is also an astonishing difference between the incidence of respiratory disease in rooms of these two types (see p. 67). The conclusions of the commission, from an exhaustive study of the effect of various ventilation conditions upon the health of 2500 children during one winter season and of 3000 children during a second season was as follows:

The analysis of the complete investigation, after equalizing the influences exerted by each school, suggests that fan-ventilated rooms of the type represented

in this study, kept at temperatures averaging between 68° and 69° F. are productive of an excessive amount of respiratory disease as compared with rooms ventilated by windows and gravity exhaust kept at 66° to 67° F. The absence rate from respiratory illness in the fan rooms is 11.1 as against 9.4 for the window rooms. The illness rate among pupils present in school is 73 for the fan rooms as against 43 for the window rooms.

Expressed in the form of a ratio, for every 100 absences from this cause in the window rooms, there are 118 absences in the fan rooms, or an excess of 18 per cent. For every 100 illnesses among those present in the window rooms, there are 170 in the fan rooms, an excess of 70 per cent.

This result is found in spite of the fact that the fan rooms are less congested, 14.7 square feet of floor space per pupil, as compared with 11.1 square feet in the window rooms. The relative humidity of the window rooms is 38 per cent; of the fan rooms 40 per cent. Eighteen per cent of the sessions in the window rooms were judged especially fresh by the nurses; whereas the figure in the fan rooms was higher, 22 per cent. The sessions judged odorous made up 17 per cent of the total in the window rooms and but 14 per cent in the fan rooms. The differences in illness rates are significant; those for the absence rates being greater than the probable error and those for the illness-in-attendance rates being more than three times the probable error.

The final conclusions of the commission in regard to these two methods of ventilation are as follows:

In final summary we may conclude that either window ventilation or plenum fan ventilation—if the plant be properly designed and operated—yields generally satisfactory results from the standpoint of air conditions in the average schoolroom. We have found it possible to maintain by either of these procedures air conditions in the schoolroom that would be considered satisfactory by all the ordinary physical tests and conditions which are reasonably comfortable and satisfactory to the occupants. The main difference lies in the fact that the air of the fan-ventilated room is likely to be about 2° F. higher, and more uniform in temperature, and that the air movement in this method is considerably greater.

We find that on the whole, other things being equal, the window-ventilated room at 67° F. is somewhat more comfortable than the fan-ventilated room at 69° F.

We find that the window-ventilated room at 67° F. is characterized by materially lower incidence of respiratory disease than the fan-ventilated room at 69° F.

It appears that 68° F. is a critical temperature as regards both comfort and susceptibility to respiratory disease; and the great advantage of window ventilation lies in the fact that the reduced air flow in the zone of occupancy permits this low temperature to be maintained.

It would seem obvious that the compulsory use of "positive" plenum systems of ventilation, supplying 30 cubic feet per minute of warm air, is not only costing the taxpayers of the United States millions of dollars but is, at the same time, working very real injury to

the health of our school children.[3] Educational authorities throughout the country are awaking to these facts and are mitigating the evil by opening windows and stopping the fans or reducing their speed. It is more than time, however, that we should strike at the root of the matter by securing the revision of state laws and regulations in the light of modern knowledge. The American Public Health Association at its St. Louis meeting in October, 1925, adopted a strongly worded resolution urging such a course.[4] It should be easy to bring the facts in the case to the attention of the

[3] It is of interest to note that the leading European countries have much more reasonable and scientific ventilation standards than those which have been imposed in the United States. In Sweden, France, and Germany legal requirements or recommended standards provide for a supply of 7–13 cubic feet per person per minute. (See *Transactions of American Society Heating and Ventilating Engineers for 1914.*)

[4] Whereas, hundred of thousands of dollars are wasted every year on this continent in the installation and operation of systems of school ventilation which are not only not beneficial but are positively harmful to the health of school children.

In the light of current knowledge, the supply of as large an air volume in school rooms as 30 cubic feet per minute, per capita, is necessarily accompanied with dangerous overheating of the schoolroom in order to avoid resulting drafts.

The use of ozone and other chemicals for treating schoolroom air has little or no scientific justification and little or no practical value;

RESOLVED: That the system of ventilating schoolrooms by fresh untreated outdoor air, admitted at the windows with gravity exhaust ducts for removing vitiated air from near the ceiling, is the most generally satisfactory method of school ventilation; and

That state laws and city regulations interfering with such scientific and economical methods of school ventilation should be repealed in the interests of the public health.

state educational authorities of Alabama, Illinois, Maine, Michigan, Minnesota, New Jersey, and Utah—of the State Health Departments of Florida, Idaho, Louisiana, Vermont, and West Virginia—of the Industrial Commission of Ohio and Wisconsin—and of the Department of Public Safety of Massachusettes. It should not be difficult to secure the necessary modification of statutory legislation in Indiana, Montana, New York, North Dakota, Oklahoma, Pennsylvania, South Dakota, Texas, and Virginia. Thus only can the dead hand of outworn hygienic theory be removed and the designers of school buildings freed to provide for our school children the most healthful air conditions at a reasonable cost.[5]

[5] At the recent session of the Ohio Legislature (1925) an unsuccessful attempt was made to substitute a standard of 10 cubic feet per person per minute for the present standard of six air changes per hour (which amounts to 30 cubic feet per minute). This would seem to be a reasonable requirement. Another way of securing the same end would be to abandon a mechanical standard entirely and to substitute a standard of actual air conditions such as the following,—adopted by the Board of Health of New York City on December 11, 1917:

1. Temperature—The temperature in rooms during periods of occupancy should register preferably from 60 to 70 degrees Fahrenheit at all times, except when the outside temperature exceeds 60 degrees Fahrenheit. This does not apply to rooms used for special purposes such as industrial places where high or low temperatures are essential and unavoidable.

2. Humidity—The relative humidity in occupied rooms should not exceed 70 per cent, except when the outside-bulb temperature exceeds 59 degrees. In no case, however, should the wet-bulb temperature exceed 78 degrees.

3. Carbon Dioxide—The carbon dioxide in occupied rooms in all

Fan Ventilation and Its Field of Usefulness

It cannot be too strongly emphasized that there is no "system" of ventilation which will ensure universally satisfactory results, any more than there is any "system" of medical treatment which will cure all diseases. Each type of building and, to a certain extent, each room, furnishes its own peculiar problems.

In general, window ventilation alone will serve for the living room, the sleeping room, and the hospital ward. Window inlets, with gravity exhaust on the plan discussed above, will ordinarily prove most satisfactory for the schoolroom, for the ordinary office, and for many factory workrooms. In the large or crowded office or workroom (particularly with special heat sources present) and in the auditorium, on the other hand, natural heat loss through walls and ceiling will generally be so

classes of buildings, should not at any time exceed 10 parts in 10,000 volumes of air in any part of the occupied spaces of the rooms.

4. Dust—The dust particles in the air of occupied rooms in all classes of buildings should not exceed 1,000,000 per cubic foot, or .004 (4 milligrams per 100 cubic feet).

5. Bacteria—The bacteria content should not exceed 100 per cubic foot.

6. Odors—The air of occupied rooms of all classes of buildings should be free from objectionable odors, which may be detected by persons entering the room from the outside air, whether the odors are of human origin or otherwise.

small relative to bodily heat production that an air supply of 30 cubic feet per person per minute (or more) will sometimes be necessary, to maintain a low temperature. Such occupied spaces cannot, as a rule, be satisfactorily ventilated by a window-gravity system and we must here resort to fan ventilation.

Two general types of fans are used in securing forced ventilation, the propeller fan and the centrifugal fan. The propeller type operates on the principle of the ordinary electric desk fan, having curved vanes which drive the air at right angles to the general plane in which the fan itself revolves. This form of fan will move considerable volumes of air but only against low pressures, and is well adapted to supplement natural ventilation when only a moderate increase in air change is essential. Propeller fans are often placed in the outer walls of workrooms for example, or over kitchen ranges, discharging outward, to accelerate natural agencies in the exhaustion of vitiated air. They are not, however, suited for use with duct systems of ventilation where the air must be moved against considerable pressure. When the pressure rises, their efficiency falls off and a back current is often created, the air flowing in one direction at the periphery and

in the opposite direction near the center of the fan.

For systems of duct ventilation the centrifugal type of blower fan should generally be used. In such a fan air is drawn in by lateral openings at the center of the plane of revolution and forced out through a tangential duct by the action of a series of parallel blades. Fans of this pattern may be used as *pressure* or *plenum fans* when they deliver to the ventilating ducts and draw in their supply freely from an air chamber surrounding them. Or they may be used as *exhaust fans* if the central opening is connected to the ventilating ducts and the delivery is to the outer air. In some buildings with very elaborate plans for ventilation both plenum and exhaust fans and ducts are provided.

Plenum ventilation is often combined with air washing or artificial humidification. In such a system the incoming air is first heated to a moderate degree (50° to 70° F., depending on various conditions) by passing through the *tempering coils,* which are lines of steam piping like those in an ordinary radiator, but so constructed as to present the largest possible surface to the rapidly moving air. From the tempering coils the warmed air passes through

the *spray chamber* or humidifier. This is a chamber filled with a fine mist of water produced by some form of spray discharge, and at its outlet end the air passes between a series of overlapping *eliminator plates* or baffles which change its direction suddenly many times. Contact with these baffle plates removes the excess of moisture which drains off from the eliminator to a collecting pan below.

Three things occur in the spray chamber, when it operates successfully. The air is humidified nearly to the point of saturation. It is cooled by the loss of the amount of heat required to transform the water taken up from the liquid to the gaseous form (5° to 10° in summertime), and it is washed free from a portion of its suspended dust particles.

Finally, on leaving the spray chamber the air passes through a second set of *heating coils,* where its temperature is brought up to the final point desired, ranging from perhaps 60° F., where the removal of the heat produced in an auditorium is necessary to 150°, where a large amount of indirect heating must be accomplished.

The temperature of the air delivered by the fan may be regulated automatically by thermostats controlling, either sections of the

heating coils, or dampers which admit a varying proportion of by-passed air, not exposed to the heating coils at all. The humidity of the air delivered can be regulated by controlling the relative temperatures of the tempering and the final heating coils since the air passing the humidifier is supposed to be saturated at the temperature at which it leaves the spray chamber and its final humidity will obviously depend on the increase in temperature to which it is subjected after this point.

From the fan chamber, the tempered air, whether it is humidified or not, is delivered to the various parts of the building by a system of ducts carried up, through, or along the walls. It may be pointed out that many systems of fan ventilation in actual use fail to give satisfactory results because the ducts are so imperfectly proportioned as to distribute the air unevenly between the different parts of the building. Thus, in one office building studied by the writer an exhaust system was installed which gave reasonably good results on the six lower floors, while on the upper floors there was either no air flow at all or vitiated air from the lower part of the building was being forced into these rooms through the supposed exhaust ducts. The problem of

the proper proportioning of air ducts is by no means a simple one, as emphasized particularly by the studies presented in the second report of the British Departmental Committee on the Ventilation of Factories and Workshops (1907). It is important that individual duct dampers should be provided so that the air supply to each room can be independently governed; and by somewhat elaborate but wholly practical systems of double or individual duct ventilation even the temperature of each room can be separately controlled to meet varying conditions of weather and occupancy. Where air is delivered to a large factory workroom by a long duct running along the ceiling, it is common practise to construct the duct of a tapering form, becoming gradually smaller from the inlet to the outlet end. Recent studies have shown that a uniform straight duct is likely to give quite as good results; but that the main duct should discharge into the room not by mere lateral openings but by short branch ducts slanted forward in the direction of the air current.[6]

The linear velocity of air maintained in systems of fan ventilation will usually vary from

[6] See *Winslow and Greenburg Public Health Reports*, July 28, 1922.

1200 to 2000 feet per minute in the main duct near the fan. As the air passes through horizontal branch ducts and vertical stacks its velocity is gradually reduced and at room inlets it is usually between 300 and 800 feet per minute. It is desirable that it should not exceed 300 feet per minute at such points in order to avoid unpleasant drafts. If, then, it is desired to provide an air supply of 30 cubic feet per minute, the inlet registers in any room should have a total area equal to 0.1 square foot per capita.

In addition to providing a given total amount of air to the room to be ventilated, considered as a unit, it is important to secure a reasonably equable distribution of air within the different parts of the room itself. Local temperature differences and other factors which affect this distribution are complex and variable. It is by no means rare to observe grotesque mistakes in actual practise such, for example, as an exhaust fan of the propeller type placed over an open window producing a strong local up current with no material benefit to the room as a whole.

There are two general systems of room air distribution in common use: the upward and the downward system. The latter plan, which

is usually employed in schoolrooms, ventilated on the fan system, brings the fresh air in at the top of the inner or warm wall of the room and takes out the vitiated air at the bottom of the same wall. It is assumed, in such a system, that heating is combined with ventilation and that the incoming air will be warmer than the general room air. In such a case the New York State Commission studies indicated that it was generally best to bring the plenum air supply in on the short wall of the room near the ceiling and to place the outlet near the floor of the same wall. The warm air shoots across the upper part of the room and then, as it cools, passes backward through the zone of occupancy.

If ventilation is frankly recognized as a procedure for supplying fresh, cool air to remove the excess heat produced within a confined space, an upward system of ventilation seems more logical. This plan involves the introduction, at or near the floor, of air cooler than the general air of the room, this air to become gradually warmed as it rises to exhaust outlets at the ceiling. In order to avoid unpleasant drafts, the admission of air cooler than that of the room must generally be accomplished through multiple inlets which in auditorium

ventilation are often placed under each seat; and even with this arrangement complaints of draft are frequent.

The results which may be obtained by the use of properly designed and operated systems of mechanical ventilation are truly remarkable. In a study made by Greenburg and the writer [7] of conditions in a large munition factory, it was found that the ordinary workrooms, where there were no special heat sources and no attention paid to ventilation, were markedly overheated (68 per cent of the rooms 70° and over in winter). On the other hand, a large annealing shop containing a row of cast-iron drum furnaces in which shells were annealed at 1200° was kept under 67° on a winter day by a system of fan ventilation capable of delivering 90,000 cubic feet of air per minute (over 30 changes of air per hour). A shell wash-shop in the same plant was less satisfactorily handled, the temperature being about 82° dry bulb and about 65° wet bulb in spite of over 20 changes of air per hour. Temporary stoppage of the fans led, however, to a rise of dry-bulb temperature to 88° and of wet-bulb temperature to 76°, a condition that proved well-nigh unbearable; even in this case,

[7] *Public Health Reports*, February 10, 1922.

the system of fan ventilation was accomplishing notable results.

Whether it is necessary or desirable to combine artificial humidification with plenum ventilation in the school or in the ordinary factory seems still an open question. In view of the prevalent conception that the dry air of the plenum ventilated schoolroom exerts a seriously harmful influence on health and efficiency, the New York State Commission devoted considerable attention to the observation of the practical effects produced by the washing and humidification of plenum air. Two groups of children were exposed during the school hours of a period of sixteen weeks, respectively, to plenum air with an average relative humidity of 28.7 per cent, and to humidified air with an average relative humidity of 42.3 per cent. Careful observations of the physical development of the pupils at the beginning and end of the experimental period and detailed examinations for the detection of physical defects revealed no difference between the two groups. Exhaustive psychological studies of mental attainments and progress in schoolwork again failed to show any difference between the two groups. From the standpoint of the incidence of respiratory disease during

the period of observation, the children exposed to humidified air showed an excess of respiratory disease among pupils in attendance but materially less absence due to respiratory disease as compared with the children exposed to ordinary plenum air. The differences observed were, however, so slight that they are probably not statistically significant.

While these observations of physical and mental conditions of pupils indicated no material influence of humidification, our experience indicated that the air of the humidified room was much less agreeable, as indicated by the opinions of teachers and observers than the air of the unhumidified room, being characterized by a more frequent occurrence of odor and stuffiness.

It should be noted in interpreting these results that the difference in humidity between the air of the two schoolrooms was not large; but it was as great as could be maintained without serious complaints of frosted windows and an excessively moist sensation. As it was, the moist room was recorded as "too moist" on 10 per cent of the sessions voted on.

It might be maintained that the temperature of the two schoolrooms was maintained at too nearly the same point (the dry room being 0.7°

F. warmer than the humidified room on the average). Here too, however, we went as far as the comfort of the occupants would permit. The humidified room was voted too cool 10 per cent of the time and too warm 9 per cent of the time, showing that an approximately comfortable rate of heat loss was maintained. All in all, this investigation suggests that artificial humidification does not produce any striking improvement in the health or efficiency of school children and that it renders the air of the schoolroom less, rather than more, attractive from an æsthetic standpoint.

Among the more elaborate procedures for ventilation which have been suggested in recent years, special mention should be made of the practice of recirculation. The recognition that ventilation is not primarily a problem of removing toxic substances but rather one of air conditioning from the standpoint of temperature and humidity led naturally to the idea of economizing heat by using the same air over and over again. In the furnace-heated house this plan is an excellent one and substantial economics can be effected by the use in cold weather of a special air inlet, drawing air, for example, from the front hall. In applying this idea to a school or factory, however, it is neces-

sary to wash the air before recirculating it to avoid the accumulation of unpleasant odors. Where such a system is in force, the air exhausted from a room is not discharged into the outer air but carried back to the fan room where it is washed by passing it through a humidifier, such as has been described above; and after its temperature and humidity have been adjusted it is sent back again to the rooms, mixed with a greater or less proportion of fresh outside air. The waste of coal involved in the discharge of exhaust air from ventilating ducts is, of course, enormous and a system like that of recirculation which promises to save from one-third to one-half of our heating costs has naturally received very serious consideration.

Dr. J. H. McCurdy and Professor F. H. Bass have reported very satisfactory results from the use of recirculated air, in the Y. M. C. A. College Gymnasium at Springfield, Mass., and in a school at Minneapolis, Minn., respectively. On the other hand, studies conducted by the New York State Commission on Ventilation in a New York City school proved distinctly unfavorable to the process. Even with most careful operation it was found impossible to keep the recirculated air constantly

free from body odors by the use of the air washer; and the deodorization of the air with ozone, a process which has been strenuously advocated in recent years, proved even more unsatisfactory. The unpleasant smell of the ozone was added to the body odor without obliterating it. Incidentally, it may be remarked that the use of ozone in ventilation is without scientific justification. It cannot disinfect air except in concentrations which are physiologically harmful, and its deodorizing effect is of very uncertain value. Recirculation may be well adapted to certain installations, as at Springfield where it has worked most satisfactorily. To advocate it as a general procedure for school ventilation, under the conditions of operation likely to obtain the country over, would seem to be unwise.

How to Attack the Practical Problems of Ventilation

The problems of ventilation are not nearly so subtle and mysterious as the layman is often inclined to believe. Nine-tenths of them can be solved by the exercise of a little common sense along the following simple lines.

A. The first step is the placing in every liv-

ing room, schoolroom, office, and workroom of a thermometer and systematic noting of the temperature recorded.

B. If the temperature is found to exceed 68°, the next step is to attempt a control of overheating by moderating artificial heat sources such as radiators or registers.

C. If overheating still continues, the effort should be made to introduce fresh cool air by adjustment of windows, transoms, and the like, providing an inlet for cool air below and an outlet for warm air above and avoiding unpleasant and dangerous drafts. Success may generally be attained by these simple means in the living room, the hospital ward, and in many offices.

D. In larger offices, in schools, and in many factory workrooms, we must go a step further and provide for a system of window-inlets and gravity-exhaust, such as was found so satisfactory by the New York State Commission on Ventilation. This gravity-window system involves three simple elements; the admission of fresh air over deflecting surfaces such as are provided by slanting window boards or tilting sash windows; the tempering of this incoming air by radiation extending across and below the windows to be used; and the pro-

vision of gravity exhaust ducts (with or without heating coils) opening from a point or points near the ceiling on or near the inner wall of the room. Such a procedure will change the air at a rate of 10 to 20 cubic feet per minute per person, amply sufficient to guard against unpleasant odors. It will maintain a moderate current of cool air, far more pleasing, and very much more healthful, than the heavy stream of warmer air produced by the fan system. It is, in general, the ideal method for the ordinary schoolroom.

E. In schools so situated that dirt, smells, or noise prevent the opening of windows—in factory workrooms which are very large and crowded or which contain special heat sources or sources of dust and fumes—and in large auditoria—gravity ventilation will not usually suffice and we must perforce turn to mechanical ventilation. It is at this point that the exercise of lay common sense gives way to that of expert knowledge; for if a fan ventilation system is to be used at all, it is essential for efficiency and economy that it should be designed by an experienced ventilating engineer.

It is important to note, however, that the installation of an adequate system of ventilation is only one part of the problem. It must

constantly be borne in mind that the factor of faithful and intelligent operation is also essential to success. No amount of skilful planning will produce a system that can work itself. Window ventilation requires the attention of those in charge of individual rooms. The most elaborate system of plenum ventilation, with automatic temperature regulation, must be watched to see that all its parts are in good working order. Constant vigilance is the price of pleasant and wholesome air conditions.

When a new plant of any kind is installed, it should be operated for a time under the supervision of its designer, with careful studies of results, as regards temperature and humidity and air circulation in different rooms and parts of rooms. Such preliminary tests would reveal many minor adjustments likely to improve results materially; and they would make it possible to formulate clear and simple rules of operation which could be turned over to the janitor or other operating agent with reasonable assurance of success.

"Finally," to quote the final words of the New York State Commission Report, "it must be emphasized in closing this discussion that the avoidance of overheating is the primary

essential in all systems of ventilation. Air change, direction of flow, and all other factors are secondary. The most important article of ventilating equipment is the thermometer; and however simple or however complex an apparatus may be installed for air conditioning, a constant and intelligent vigilance in regard to operating and overheating is the price of health and comfort."

CHAPTER IV

SPECIAL PROBLEMS OF FACTORY VENTILATION

The Problem of Atmospheric Poisons Illustrated by Carbon Monoxide

In the last two chapters we have considered only those effects upon the atmosphere which are due to human occupancy and to the influence of sources of heating and lighting when the latter are operating under the best conditions. In the course of many industrial processes, fumes and dusts of a specifically deleterious nature may be liberated and the problems which arise in this manner are so serious as to deserve special consideration.

Of the atmospheric poisons which may create such industrial hazards, carbon monoxide is one of the most important; and this substance forms a logical mode of approach to the subject since it threatens life and health, not only in the factory but in the garage and in the home as well.

Carbon monoxide is produced, instead of

carbon dioxide, whenever incomplete combustion takes place, as about blast furnaces, in tailor's shops where pressing irons are heated, in garages and in rooms heated by gas heaters. Unlike carbon dioxide, this gas is a very deadly poison. It possesses the power of uniting, as oxygen does, with the hemoglobin of the blood and in so doing reduces the oxygen-carrying power of the red blood cells so as to produce serious and often fatal results. In the presence of large concentrations of carbon monoxide the victim may fall into unconsciousness, quickly followed by death, without any warning symptoms whatever. Under other conditions there may be such premonitory symptoms as throbbing or fullness of the head, roaring in the ears, blurring of vision, shortness of breath, and weakness of the legs. Long exposure to small amounts of the gas, as among garage workers and pressers of clothes, produces a chronic poisoning accompanied by fatigue, headache, dizziness, shortness of breath, digestive and mental disturbances. One-half of one part per thousand of carbon monoxide has proved poisonous, and exposure to two or three parts per thousand for half an hour may be dangerous to life.

In industry, the greatest number of cases

of carbon monoxide poisoning occur as a result of exposure to producer and blast-furnace gases in the steel and allied industries. Among less than a thousand men employed about Illinois blast furnaces, 13 fatal cases occurred during a period of four years with 65 severe and 216 mild cases of poisoning a year.

So far as the domestic hazard from carbon monoxide is concerned, the *American Journal of Public Health*[1] points out that

"The flueless gas heating stove is responsible for most of the poisoning in this country, and of these the so-caller 'radiant heater' has been found to be the most dangerous. Gas hot plates and cooking stoves cause a certain amount of poisoning, but chiefly when they are used for heating purposes since the burning is then continued for a number of hours at a time. Gas water heaters also cause some deaths and asphyxiations. Carbon monoxide is especially liable to be formed by the 'radiant' heater when the 'glowers' are incandescent more than three-fourths of the distance from the top to the bottom. Even the best types of radiant heaters are subject to this condition, while the cheaper types generate CO under almost all conditions of operation.

During the winter of 1922–23 in the State of Ohio, there were 64 deaths and 113 cases of partial asphyxiation. Of these, 41 deaths and 46 asphyxiations were due to heaters, generally of the radiant type. For the winter of 1923–24 there were in the State of Ohio 61 deaths,

[1] *American Journal of Public Health*, Vol. XV, January, 1925, pp. 57–8.

42 of which were due to gas heaters. These cases are not taken from newspaper reports, but have been investigated and authentically traced to CO poisoning by the officers of the State Board of Health. A health officer writes: 'I have myself viewed the bodies of a father and mother and four children asphyxiated by a most innocent looking, small type, radiant heater; also the bodies of a bridal couple asphyxiated on their wedding night by a portable radiant heater, that is, one which can be carried around by a bail handle, and having only five clay glowers.' Poisonings in Ohio are more than usually significant since the natural gas widely used in that state contains no carbon monoxide and is nontoxic otherwise.

The most important measure to prevent the occurrence of asphyxiation by gas heaters is an abundant supply of flues to carry off all waste products. The best types are set back in fireplaces which have chimney flues. It is important also to see that the flues are open and have sufficient draft under all weather conditions. Water heaters in bath rooms are particularly dangerous on account of the small size of the rooms, and from the fact that they are kept closed while in use. The instantaneous heaters are especially apt to generate considerable amounts of CO. In an ordinary sized bath room, enough gas can collect within fifteen minutes to asphyxiate the bather. In Ohio this matter has been the subject of consideration by the State Legislature where a bill was drafted providing for the proper designing and construction of gas heaters, for their testing and approval under the State Department of Health, for the fluing and ventilating of all gas heating appliances, and plac-

ing on each piece of apparatus a stamp by the manufacturer showing such approval. The bill did not pass, but it indicates the importance attached to such poisoning.

Above all, however, it is in connection with the automobile that the danger of carbon monoxide poisoning has become most serious. We can scarcely pick up a paper in winter without reading of accidents due to the liberation of carbon monoxide from engines kept running in closed garages. Furthermore, it seems probable that aside from acute and fatal cases of poisoning there is a widespread chronic intoxication among garage workers and others exposed to this gas. A recent study made by Ciampolini for the State Department of Labor of New York showed that out of 31 garages 24 showed carbon monoxide in the air, 17 of them in an amount in excess of 0.1 per cent, which is set as a danger limit by competent authorities; while of 42 workers in these garages who were physically examined 29 showed evidence of carbon monoxide in their blood and many exhibited definite clinical symptoms of carbon monoxide poisoning. Henderson and Haggard believe that, even out-of-doors, dangerous concentrations of carbon monoxide may be reached under conditions of

crowded street traffic. The remedy suggested by these investigators is the equipment of all closed automobiles with a vertical exhaust, discharging above the roof so as to carry the poisonous gases away from the breathing zone outdoors and to discharge them into the range of roof ventilators in the garage. In view of the seriousness of the hazard involved, this policy deserves and is receiving the very serious consideration of health authorities throughout the country.

Lead Poisoning

Next in important to carbon monoxide as an industrial poison we may without question place the salts of lead. Metallic lead, itself, is not poisonous because it is not soluble in the body fluids but the carbonate (white lead) the acetate (sugar of lead) and the oxides (red lead, litharge, etc.) are all exceedingly toxic. The hazard involved in the use of these substances is greatly increased by the fact that lead is a "cumulative" poison; instead of producing an acute effect and then being excreted it is, to a large extent, stored up in the body, being liberated when the reaction of the blood is slightly changed to produce serious and far-reaching effects.

Poisonous lead salts, for the most part, enter the body by way of the digestive tract or as a result of dust breathed into the lungs although it also is possible for poisoning to take place by absorption through the skin. The normal way by which lead gets to the digestive tract is, however, by the swallowing of inhaled atmospheric dust. The trades chiefly affected are white-lead making, paint mixing, and dry color grinding, manufacture of storage batteries, the making of porcelain and enamelware and, above all, painting, particularly the painting of automobile bodies and similar tasks which involve spray processes and dry sandpapering. Over one hundred different industries have, however, contributed well-defined cases of lead poisoning to the literature of the subject.

One of the first signs of lead poisoning is a gradually increasing pallor, accompanied by well-defined changes in the number and appearance of the red blood cells. A peculiar bluish line ("the lead line") on the margin of the gums close to the teeth sometimes aids in diagnosis. Constipation is common and sharp attacks of pain in the abdomen ("painter's colic") are likely to occur. The nervous system is particularly affected and paralysis of

the wrists ("wrist-drop") or other joints frequently results. Meanwhile, far-reaching toxic effects are exerted upon the blood vessels and kidneys and there can be no doubt that many deaths which are attributed, perhaps years afterwards, to degeneration of the circulatory system are really the ultimate effects of lead poisoning.

Dr. Alice Hamilton, in a series of investigations conducted for the Federal Government, found some years ago that among white lead workers there had occurred 18 cases of lead poisoning per 100 employed, among porcelain sanitary ware workers 21 cases per 100, among electric storage battery workers, 18 cases per 100. Harris, in New York, found that 53 per cent of 304 painters showed symptoms of lead poisoning when they were carefully examined by both climical and laboratory tests. In the state of Ohio, to take only one recently reported body of statistics, there were reported to the State Department of Health during a period of ten years, 1295 cases of industrial lead poisoning, the vast majority of them due to the inhalation of lead dust and fumes. In the hospitals of Detroit, during three years, there were treated 108 cases of lead poisoning, of which 67 occurred in a single factory among

a group of men employed in the dry sandpapering of lead paint.

Other Industrial Poisons

Carbon monoxide and lead are the most important of the purely industrial poisons, but there are many others which affect smaller groups of workers in a more or less intensive degree. Mercury salts which cause the "hatter's shakes," arsenic and other heavy metals, the fumes of brass and zinc, the oxides of nitrogen which produce acute and often fatal injuries to the lungs of munition and chemical workers, the irritant halogens, and a whole host of organic poisons such as wood alcohol, carbon bisulphide, anilin and benzene and their derivatives, the nitrobenzols and trinitrotoluene, are all common and serious industrial poisons. The dusts from certain tropical woods produce painful skin irritations similar to those which result from ivy poisoning. The increasing use of benzol in industry has attracted special attention of late; a committee of the National Safety Council has been studying the problem with the result that 15 deaths and 83 more or less serious illnesses were traced to this substance during a period of two years.

Furthermore, the committee in the examination of a group of 81 workers exposed to benzol fumes found that 32 per cent of them showed a white-blood-cell count so low as to be strikingly suggestive of benzol poisoning, indicating, as in the case of carbon monoxide and lead, that, besides the more obvious acute cases, there exists in industry a considerable amount of milder undetected chronic poisoning.

It is unnecessary here to go further into the problem of the various and manifold toxic agents to which the industrial worker may be exposed. It is sufficient for our present purpose to note that in a wide variety of industrial processes grave dangers to health exist as a result of the presence of various poisonous substances; that atmospheric fumes and dusts are the agents by which such toxic materials are most commonly distributed; and that the control of these hazards by special ventilation is a problem of pressing moment.

Atmospheric Dust and Industrial Tuberculosis

In addition to the presence of fumes and dusts of a specifically poisonous nature, there is another type of hazard which, in the aggregate, is even more serious and important, re-

sulting from exposure to certain types of dust which produce a specific diseased condition of the lungs and predispose to the development of tuberculosis. This danger has attracted attention from very early times. Hippocrates speaks of the metal miner as a man who "breathes with difficulty" and "is of pale wan complexion." Agricola in his book on metallurgy (published in 1556) states that "some mines are so dry that they are entirely devoid of water, and this dryness causes the workman even greater harm, for the dust which is stirred and beaten up by digging penetrates into the windpipe and lungs, and produces difficulty in breathing, and the disease which the Greeks call asthma. If the dust has corrosive qualities, it eats away the lungs, and implants consumption in the body; hence in the mines of the Carpathian Mountains women are found who have married seven husbands, all of whom this terrible consumption has carried off to a premature death." Ramazzini, in his famous work on the *Diseases of Artificers and Tradesmen* (1700) states that stone cutters "oftentimes suck in, by inspiration, the sharp, rough and corner'd small Splinters or Particles that fly off; so that they are usually troubled with a cough,

and some of 'em turn Asthmatick and Consumptive." He adds: "And in dissecting the corps of such Artificers, the lungs have been found stuffed with little Stones. Diemerbroek gives a curious Relation of several Stonecutters that dy'd Asthmatick, and were open'd by him; in whose Lungs he found such heaps of Sand, that in running the knife through the Pulmonary Vesicles, he thought he was cutting some Sandy Body."

How little the problem has changed in 200 years is indicated by the following letter written to the author by a physician in a certain Massachusetts town where there is located an ax factory. He says:

I have been in practice in —— since 1863, with the exception of some thirteen years following 1872. I have seen quite a number of cases of so-called grinders' consumption. I have examined one case *post mortem.* I found the smaller bronchial tubes thoroughly filled with the grindstone grit; the lung in the lower part looked and felt like the liver after cooking. The symptoms are excessive shortness of breath on slight exertion, dry cough and great prostration. The grinders are from the Polanders and Finns for the past dozen years. The disease takes hold of them more frequently, and is more rapidly fatal than among the grinders of former years and of other nationalities. When I came here forty years ago I found the victims among the Yankees who

had ground some 20 years before. Those would grind 18 to 20 years before having to give it up. The French-Canadians were then grinding. They could work 12 to 16 years. They became frightened off and the Swedes took up the work. They would get the disease in 8 or 10 years. Now the Finns and Polanders are at it, and they last only 3 to 5 years, and the disease is more common among them.

It has been pointed out in Chapter I that ordinary indoor air or street air will normally show about 100,000 dust particles per cubic foot when examined by the Palmer water-spray apparatus. In dusty factories, on the other hand, the counts will rise to millions (2,086,000 in an iron-grinding shop, 3,750,000 in a mattress-renovating establishment, 6,791,000 in a cement mill, 15,800,000 in an ax-grinding shop, 60,880,000 in a sand-blast chamber, 159,779,000 in an abrasive factory).[2] The amount of dust present is, however, much less important than the kind. It is probable that the inhalation of very large amounts of dust of any type produces some irritation of the mucous membranes and may perhaps favor the development of acute diseases of the respiratory tract such as bronchitis. So far as the

[2] Winslow, C.-E. A. and Greenburg, L., "Industrial Tuberculosis and the Control of the Factory Dust Problem," *Jour. Ind. Hyg.*, Vol. II, 1921, pp. 333 and 378.

dusts of vegetable origin are concerned, however, there is little or no concrete evidence of even such danger as this and the six million dust particles per cubic foot in the mattress factory cited above would be much less harmful than one-tenth as many particles in a grinding shop.

The inhalation of such dusts as those produced in the coal and cement industries, on the other hand, produces quite definite pathological changes in the lungs, characterized by a process known as fibrosis. Among coal miners, this disease is known as "anthracosis" or coal miners' asthma. Such a condition as this markedly predisposes to acute respiratory diseases such as bronchitis and pneumonia. Dublin found that the influenza-pneumonia mortality during the epidemic of 1918 was twice as high among coal miners as in the general industrial population. Exposure to coal and cement dust, while it thus favors acute respiratory infections is associated with a low, rather than a high, incidence of pulmonary tuberculosis—as indicated in the table on p. 153 cited from Hoffman.[3]

[3] Hoffman, F. L., "Mortality from Respiratory Diseases in Dusty Trades," *U S. Bureau of Labor Statistics*, Bull. 231, June, 1918.

MORTALITY IN COAL MINING DISTRICTS OF PENNSYLVANIA COMPARED WITH REST OF STATE

District	Pulmonary Tuberculosis	Other forms of Tuberculosis	Other respiratory Diseases
Scranton	80	17	261
Wilkes-Barre	75	19	212
Rest of State	110	16	184

A much more serious effect is noted with dusts containing silica, which markedly predispose to tuberculosis as well as to pneumonia and bronchitis. Among metal miners, marble and granite workers, sand blasters, potters, grinders and polishers, where such silica dusts are present (contributed either by the materials worked upon or by the grinding wheels themselves) we find a very different picture from that revealed among the miners of coal or the cement workers. In such trades, as we shall see, the tuberculosis death rate may rise to five or ten times its normal figure. The exact cause of this difference is by no means obvious. It appears that silica dust is less readily removed from the lungs than is coal dust and that it causes a more marked degree of fibrosis. Why this is the case and whether this is the sole cause of the greater incidence of tuberculosis we do not know. Krause believes that the effect of the silica dust is largely due to the extent of the fibrosis and consequent

blocking of the lymph channels of the lung. The English students of this problem are inclined to hold that colloidal silica is formed and exerts a specific chemical effect upon the defensive forces of the body. Whatever the explanation, the facts are very clear.

The whole problem of the incidence of tuberculosis in the dusty trades has been somewhat confused by the careless use of industrial insurance statistics based on the ratio of tuberculosis deaths to total deaths and involving the fallacious comparison of tuberculosis ratios for so-called dusty trades with similar ratios for the general population as a whole—ignoring entirely important differences in social and economic status.[4] For at least two groups of workers in the United States exposed to silica dust, however, we have full and controlled data. For the granite cutters of Vermont Hoffman[5] gives the following striking data. The steady increase of mortality among the granite cutters is attributed to an increasing dust hazard created by the use of pneumatic tools.

[4] Hoffman, F. L., "Mortality from Respiratory Diseases in Dusty Trades," Bull. 207, *U. S. Bureau of Labor Statistics*, June, 1918.

[5] Hoffman, F. L., "The Problem of Dust Phthisis in the Granite Stone Industry," Bull. 293, *U. S. Bureau of Labor Statistics*, May, 1922.

MORTALITY FROM PULMONARY TUBERCULOSIS AMONG GRANITE CUTTERS COMPARED WITH THAT OF THE GENERAL ADULT POPULATION OF VERMONT

Period	Deaths per 100,000 Population	
	Granite Cutters	Adult Population of State
1896–99	394	190
1900–4	353	166
1905–9	719	149
1910–14	801	120
1915–18	1064	108

An even more startling case is that of a Connecticut ax factory studied by Drury.[6] The factory is situated in an otherwise agricultural district and, through the circumstance that both the superintendent and the medical consultant of the factory had been in the employ of the company for twenty years, it was possible to follow up every death certificate in the four adjoining towns and determine the actual occupation of the deceased. The results obtained are indicated in the table on p. 156.

Thus, we find the entire population of the mill district showing a tuberculosis rate of 200 as compared with 150 for the state as a whole. The mill population itself has a rate rising to 650, and the group of polishers and grinders

[6] Drury, W. H., "The Incidence of Tuberculosis among Polishers and Grinders in an Ax Factory," *Public Health Reports*, Vol. 36, Feb. 4, 1921, p. 159.

MORTALITY FROM PULMONARY TUBERCULOSIS AMONG THE EMPLOYEES OF A CONNECTICUT AX FACTORY AS COMPARED WITH THAT OF THE POPULATION OF ADJACENT TOWNS AND OF THE STATE AS A WHOLE

1900–1919

	Deaths per 100,000
State of Connecticut	150
State of Connecticut, male population	170
Ax factory district (3 towns)	200
Employees of Ax Factory, all	650
Employees of Ax Factory, polishers and grinders	1900
Employees of Ax Factory, all others	160

the astounding rate of 1900. The other employees of the mill are not entirely comparable in age, race, and general social and economic status with the polishers and grinders, but it is evident that the high death rate among the polishers and grinders, who suffer from a tuberculosis death rate over ten times the normal rate, is primarily due to the hazards of their occupation. Nor is tuberculosis the only form in which they pay a penalty for their hazardous employment. Dr. Drury reports that the mortality from pulmonary infections other than tuberculosis for the period 1900 to 1919 was 430 per 100,000 for the polishers and grinders, as compared with 170 for the other employees of the ax factory.

That industrial tuberculosis is by no means a minor hazard, affecting only a few isolated groups of workmen, is clearly seen by refer-

ence to the reports of the Registrar-General of England and Wales which give data much more complete than any which are available in this country. If we turn to the last report (for 1910–12), we find that there are ten occupational groups which show a general mortality from all causes more than 50 per cent in excess of the average for all occupied males. Of these ten occupations four are trades exposed of silica dust (cutlers and scissors makers, stone workers and masons, file makers and tin miners). The other six are either occupations specially exposed to alcoholism or casual trades like costermongers and laborers where selection of the unfit plays a predominant part in the high death rate. Dust and alcoholism seem, therefore, to be the most significant of all occupational hazards; and when we turn to the specific problem of pulmonary tuberculosis, the situation is of course even more striking as indicated in the table on p. 158.

These figures are not in terms of deaths per 100,000 but in the form of arbitrary comparative mortality figures. I have, therefore, included at the top of the table the comparable figure for all occupied males and the lowest figure cited for any occupation, that for clergy-

COMPARATIVE MORTALITY FROM PULMONARY TUBERCULOSIS IN CERTAIN OCCUPATIONS

ENGLAND AND WALES, 1910–1912

All occupied males	141
Clergymen	45
Coal miners	75
Messengers, porters, watchmen	252
Seamen, etc., merchant service	257
Potters, earthenware manufacturers	282
Tool, scissors, file, saw, needle makers	306
Inn, hotel servants	309
Lead miners	335
Costermongers, hawkers	419
File makers	434
Cutlers, scissors makers	466
Tin miners	678

men; and also the figure for coal miners to compare with that for tin miners below. It will be noted that the rate for tin miners (with silica dust) is nearly ten times that for coal miners (without silica dust). I have included in this table every occupation given by the Registrar General with a comparative mortality figure for tuberculosis over 250; and it will be noted that of the ten occupations six are occupations exposed to silica dust, including all of the three in excess of 420. It seems clear that the menace of industrial tuberculosis constitutes a problem of the first importance, a problem whose gravity even specialists in industrial hygiene have scarcely fully realized.

Preventive Measures for the Mitigation of Dangers from Industrial Dusts and Fumes

The first problem to be considered in connection with such hazards as those which have been discussed in preceding pages is the possibility of eliminating the original source of the danger. In the case of lead poisoning among painters, for example, the only really satisfactory procedure is the substitution of zinc paints for the poisonous lead compounds, such as has been brought about to a limited degree through legal regulations in force in France. In the case of carbon monoxide, the proper construction of gas heating appliances will go far to mitigate the danger.

Again, the harmful substance may be used, but may be handled in enclosed containers so that its escape into the atmosphere is minimized. In the manufacture of white lead, many processes are now carried out under water or oil so that practically no dust need be present in the air of the workroom; and many benzol processes are rendered safe by carrying them out in a system of closed containers.

Similarly, dusty processes may be rendered less hazardous by the use of wet or enclosed

processes. In the South African mines the use of water sprays has cut the dust content of the air to less than a tenth of its former figure. It is important, however, in all such cases to check up the results attained by actual determination of the dust content of the air. It has often, for example, been assumed that wet grinding was necessarily, and always, a less dangerous process than dry grinding. As a matter of fact, however, wet grinding with friable wheels of natural sandstone may be a much more dusty process than dry grinding with artificial grinding wheels. The enormous tuberculosis mortality recorded above for the Connecticut ax factory was the result of a wet grinding process on natural sandstone wheels, associated with a dust content of 15,800,000 dust particles per cubic foot.

Control of Dust and Fumes by Special Exhaust Ventilation

The method which is most generally available for protection against the industrial hazard of fumes and dusts is the installation of local exhaust ventilation, sufficiently powerful to remove the toxic or otherwise harmful substances from the point where they are pro-

duced. We have pointed out how this principle of exhaust ventilation is applied in its elementary form in the provision of flues to carry off the carbon monoxide formed by gas heaters. In factories where such products as benzol are used, the work places may be equipped with hoods connected by ducts with exhaust fans which, if properly designed and operated, often prove highly efficient. It is, above all, in connection with grinding and polishing wheels and similar dust-producing devices that the principle of local exhaust ventilation finds its most general application. The chief conditions essential to the success of an exhaust system for the removal of dust from grinding and polishing wheels are four in number: the design of the hoods themselves, so that the point where the dust is generated may be covered as completely as possible without interfering with the work, and as closely as possible so that a full suction velocity may be maintained; the arrangement of the suction draft so that it may operate with, and not against, the centrifugal force which throws the dust particles from the wheel; the elimination of all obstacles between the hood and the main exhaust duct which may decrease the velocity of suction; and the maintenance of an ade-

quate suction head in the main exhaust duct itself.

Observations made by Greenburg and the writer show that such systems of special exhaust ventilation may keep the air of a grinding shop almost as free from dust as the atmosphere of an ordinary room. In one typical workshop, with forty-nine polishing wheels more or less constantly in operation, the dust content of the air was kept down to 200,000 particles per cubic foot with the exhaust system in operation, while, when the velocity of the exhaust fan was reduced, the count rose to 863,000 particles.[7]

Wherever special hazards exist in the form of dusts or poisons, the installation of special systems of local exhaust ventilation becomes a matter of the first importance.

Protection of the Worker by the Use of Masks and Respirators

Finally, in certain industrial processes as in packing operations, in marble and granite working, and in the sand blasting of large castings, it is impossible by any of the means pre-

[7] Winslow, C.-E. A., Greenburg, L., and Angermyer, H. C., "Standards for Measuring the Efficiency of Exhaust Systems in Polishing Shops," *Public Health Reports*, Vol. 34, 1919, p. 427.

viously described to keep the air of the workplace free from dangerous concentrations of mineral and metallic (or poisonous) dusts. In such cases as this, the only alternative is the wearing of respirators which filter out the dust particles from the air before it is drawn into the respiratory tract, or of helmets which exclude the dusty atmosphere more or less completely from the mouth and nose and supply pure air for breathing from some other source. All such devices are uncomfortable and irksome to the wearer and the necessity for using them should be avoided wherever possible by the installation of the other devices which have been considered above. In certain employments, however, the respirator or helmet offers the only possible means of protection.

How effective these devices may be (particularly the helmet with positive air supply) is indicated by the table on p. 164, from studies conducted in a Bridgeport sand blast chamber.[8]

Respirators for protection against dusts are usually made of rubber fitting over the mouth and nose and including a filtering layer of cloth or sponge. Their efficiency varies widely and

[8] Winslow, C.-E. A., Greenburg, L., and Reeves, E. H., "The Efficiency of Certain Devices Used for the Protection of Sand Blasters against the Dust Hazard," *Public Health Reports*, Vol. 35, 1920, p. 518.

EFFICIENCY OF RESPIRATOR AND HELMET IN CONTROLLING THE DUST CONTENT OF AIR FROM A SAND BLAST CHAMBER

Source of Air	Average Dust Particles per Cubic Foot
Untreated air of chamber	60,880,000
Air passed through respirator alone	4,549,000
Air passed through helmet and respirator	2,047,000
Air passed through helmet alone but with positive air supply	368,000
Air passed through helmet with positive air supply and respirator	156,000

requires careful study in the individual case. For protection against chemical fumes devices are provided like the gas masks used in the war, with a layer of some absorptive chemical in the chamber through which the incoming air enters, selected to take care of the particular toxic gas likely to be present. The use of a helmet, supplied through a tube with fresh air creating an outward current through its openings, will often perhaps serve better than any of these filtering devices, and will also prove more comfortable. It can be used, of course, only where the worker remains in a given place so that the air supply for the helmet can be easily maintained.

CHAPTER V

CLIMATE AND SEASON AND THE HYGIENE OF THE SKIN

General Relations between Climate and Season and Disease

In the light of our modern conception of ventilation, as essentially concerned with maintaining physical conditions suitable for an ideal rate of heat loss from the surface of the body, it is obvious that the influences of climate and season form an integral part of the whole problem. In warm weather the whole world may be considered to be "badly ventilated"; and in very cold weather an opposite type of harmful influence is manifest, to which we have thus far given little consideration in our discussion of the question of indoor air conditioning.

It is a fact which has long been familiar to the most casual student of vital statistics that, in temperate climates, the general death rate

shows two regular seasonal maxima—in late summer and in late winter. Two distinct groups of causes of death are chiefly responsible for these peaks—the warm weather diseases such as infant diarrhea, cholera, typhoid fever, yellow fever, and malaria; and the cold weather diseases such as pneumonia, bronchitis, tuberculosis, diphtheria, scarlet fever, and measles. Geographically, we find the same general difference in incidence, the "summer diseases" being also diseases which are particularly characteristic of the warmer regions and the "winter diseases" being most prevalent in colder climes.

In the case of diseases like malaria and yellow fever the seasonal curve is, of course, governed entirely by the effect of temperature upon the breeding of the mosquitoes or other insects which serve as the agents for the transmission of the germs in question. In diseases like typhoid fever a part of the summer prevalence is, no doubt, due to similar indirect influences such as the presence of flies, the increased consumption of uncooked foods and the exposure to unusual insanitary conditions on vacation. Similarly, the excess of acute communicable and respiratory infections in winter may in part be the result of intimate

indoor association, with consequent greater opportunity for contact infection.

Dr. Charles E. North[1] has suggested that the prevalence of intestinal diseases in summer and of respiratory diseases in winter may be in considerable degree dependent on the relative distribution of the blood supply in different parts of the body as a result of external temperature conditions. In summer, he assumes that the blood is largely in the superficial parts of the body and the resistance of the intestinal walls is lowered by their consequent condition of anemia; while in winter the blood is in the inner organs and the mucous membranes of the nose and throat show a similar lessened resistance as a result.

This may well be one factor in the situation; but the problem is a highly complex one. The vital forces ebb and flow with the seasons in a more or less regular cycle, as a result of temperature, sunlight, and many other factors. The prevalence of rickets shows a very regular seasonal curve, for example, with a maximum in April, paralleled by corresponding variations in the organic phosphates of the blood—a cycle presumably related most closely to the sunlight factor. The common use of "spring

[1] *American Journal of Public Health*, Vol. III, p. 230.

medicines" is an instinctive testimony to the lowered vitality which follows the winter season in a climate like that of New England; and this lowered vitality, no doubt, plays a large part in the late winter maximum of tuberculosis and pneumonia. Even a disease like typhoid fever, which is most commonly contracted in fall, shows a higher ratio of deaths to cases in the second quarter of the year than at any other season.

Recent Statistical Studies of Climate and Season in their Effect on Health and Efficiency

The effect of climate and season upon physiological state has in the past been approached from a more or less crude and empirical standpoint. During the past ten years, however, the researches of my colleague, Professor Ellsworth Huntington,[2] have raised the whole subject to a new plane and placed our knowledge of the influence of climatic conditions upon a solid statistical basis.

From the standpoint of physical efficiency, Huntington finds that in the northern United States there is a very regular seasonal curve in the output of factory operatives in Connec-

[2] Summarized in *Civilization and Climate*, Third Edition, Yale University Press, 1924.

ticut, Pennsylvania, North Carolina, and Georgia, with maxima in spring and fall and minima in winter and summer. In Florida, as we should expect, the winter minimum almost disappears, while the summer minimum becomes very pronounced. An exactly similar curve for mental efficiency is found by plotting the average examination marks attained by students at West Point and Annapolis. The mean daily temperature most favorable for factory work is between 59° and 65°, the New England operatives being most productive at 59°, the cigarmakers of Florida at 65°. On the other hand, the mean twenty-four temperature most favorable for mental work is much lower, about 38° F.

In another exhaustive series of studies, Huntington has investigated the relation between atmospheric temperature and humidity and the total death rate, finding the same essential phenomenon—an optimum temperature point, above or below which the death rate rises. This optimum appeared to be as low as 58° for northern Italy and as high as 70° for California, but in British Columbia, the eastern northeastern, southeastern, and central United States, southern Italy, southern and northern France it fell between 62°

and 65°, with 64° as the general mean. A decrease of 10° below this minimum causes a 10 to 25 per cent increase in the death rate. Such a daily mean of 64° corresponds roughly speaking to a diurnal temperature of 70° with a fall to 60° at night.

The correlations which were disclosed in this first study were gross seasonal effects which might in large measure have been produced by various cyclical factors, indirectly rather than directly related to atmospheric conditions. A later investigation of Huntington's deals with the relation between mortality in the large cities of the United States and the departure, in regard to certain given atmospheric conditions, of each month of the year from the average condition for that month in that particular city. This admirably planned study showed that in general abnormally warm weather for a summer month was distinctly harmful and for a winter month distinctly beneficial. An exhaustive analysis in regard to the influence of winter temperature upon mortality on successive days after the day upon which the temperature in question was recorded indicates that high temperature is rather unfavorable than otherwise on the day on which the high temperature occurs but very

favorable during the three or four succeeding days so far as mortality of children under five is concerned and on the whole somewhat favorable for mortality over five and for mortality from pneumonia for a longer period thereafter.

In regard to the influence of relative humidity, Huntington's results indicate that, if we ignore the distinction between season and weather, a mean daily humidity of 80 per cent is associated with a minimum general death rate while higher or lower humidities show increasing mortality. Factory work is also most efficient with a rather high humidity. Besson has found that high humidity in Paris is associated with low mortality and Huntington reports similar results for pneumonia in New York and for post-operative deaths in Boston hospitals (although at high temperatures, as would be expected high humidity proved harmful). In Huntington's studies of the influence of deviation from the normal for a given month, high relative humidity was almost always beneficial. On the other hand, he found that diurnal variations in humidity showed no appreciable effect upon mortality.

It is somewhat surprising, in view of what we know of the general physiological effects

of atmospheric humidity, to find that such high relative humidities as those indicated by Huntington are favorable to low mortality. It must be remembered, however, that a mean twenty-four humidity of 80 per cent generally means a humidity of under 60 per cent in the day time, with high humidities at night. There is no necessary inconsistency between the fact that such a relative humidity in the outdoor atmosphere is most favorable to health and the conclusion of the New York State Commission on Ventilation that raising the relative humidity of the schoolroom from 30 per cent to 40 per cent has no detectable influence upon health and efficiency. The net effect of the average outdoor atmosphere for the twenty-four hours may well be very different from that of the schoolroom continued for a few hours only every day.

Finally, Huntington believes that changeability is a third factor of major importance in an ideal climate. The efficiency of factory operatives appears to show an increase, with either a slight rise or a slight fall in temperature, and a decrease, with more marked changes in either direction. The mortality rate for the large cities of the United States displays a distinct tendency to decrease in

stormy or changeable weather. The daily mortality in New York City shows a marked increase with sudden rise in temperature, particularly at ages under five. It is not quite clear to what extent such influence can properly be said to be due to changeability *per se,* rather than to the mere fact that the temperature is raised or lowered. It does seem certain, however, that a moderate drop in temperature is stimulating and beneficial.

The importance of a cool, fairly moist, and moderately changeable climate as one vital factor in the development of a high civilization is brought out by Huntington in an exceedingly interesting fashion. He points out that an ideal climate, as measured by these criteria, exists today in but six places on the earth's surface. There are two large areas of this kind in Western Europe and in the northeastern United States and southeastern Canada, respectively; and there are four small areas of the same type, in Japan and Korea, in New Zealand and southeastern Australia, in the southern part of South America, and along the Pacific coast of North America. It will be obvious that these zones of ideal climate correspond exactly to the centers of culture which dominate the world today; and Huntington be-

lieves that the rise and fall of world civilization in the past has in large measure been determined by cycles of climatic change which have endowed, first one land, and then another, with such atmospheric conditions essential to maximum progress.

Infant Mortality and Summer Heat

One of the most important single problems in this general field of climatic influence is the effect of high summer temperatures upon infant mortality. Long ago, Rietschel, in Dresden, found that at a temperature of 86° the delicately balanced heat-regulating mechanism of an infant often becomes deranged and a state of fever may set in. Liefmann and Lindemann in Berlin [3] showed that two distinct types of infant mortality may be noted in summer. The first days of very high temperature lead to sharp attacks of heat stroke with pronounced nervous symptoms, while the prolonged, though often less extreme, heat of August is associated with more protracted disease in which intestinal symptoms play the prominent part. The feeding of infants on breast milk

[3] Reviewed by J. W. Schereschewsky, "Heat and Infant Mortality," *Public Health Reports*, Vol. 28, Dec. 5, 1913, p. 2595.

or pasteurized milk is a reasonably effective protection against the latter type of disorder, but it is also important to guard against excessive temperatures in every way possible. Flügge, Rietschel, and others in Germany, and Helmholtz in Chicago have shown that, even when the outdoor temperature is not very high, records of 85° to 95° are common in the crowded tenements. An outdoor temperature of 72° to 75° is often sufficient to produce very dangerous overheating in the homes of the poor.

An application of artificial ventilation devices which deserves far more attention than it generally receives is the possibility of artificial cooling of the air of occupied spaces in warm weather. It is somewhat strange that we freely pour out money to heat, and often to overheat, our buildings in winter while we so seldom think of cooling them in summer. Yet one procedure is quite as practical as the other (though more expensive) and perhaps quite as important from the standpoint of hygiene.

The passage of air through a humidifier, as pointed out above, effects an appreciable degree of cooling; or the incoming air may be cooled by passing it over coils through which cold water or brine is circulated. One of the

leading banking houses of New York is provided with a system of ventilation used with steam coils for heating in winter and with brine coils for cooling in summer. A temperature about 10° below that of the outside air is maintained in warm weather, and the writer was told by a member of the firm that there was only one serious objection to the plant—that people who came into the office in summer could never be persuaded to finish their business and go out again. One of the principal hotels in Chicago has an artificially cooled dining-room that is a constant satisfaction to those who visit it. The Mt. Sinai Hospital in New York has provided a specially cooled room for young children and in view of the direct relation between heat and infant mortality this would seem to be a particularly important application. It seems likely that cooling of the air of occupied spaces in warm weather is likely to be much more extensively developed in the future.

Shelter from the Elements—Its Use and Abuse

Food, clothing, and shelter are often grouped together as the three fundamental physical needs of human life; and the last two

have to do, primarily, with protection against the effects of extreme atmospheric conditions. It is true that many other than physical elements enter into our conception of the home. Even in the caves of Altamira and the Dordogne æsthetic needs were fulfilled by the marvelous wall paintings of our prehistoric ancestors. Yet these primitive men sought the caves primarily for shelter against the elements and protection against wild beasts and human foes. Much the same fundamental motives underlie the construction of our dwellings even today.

Shelter against the cold of winter is, then, an essential and important factor in the promotion of human health and welfare. As pointed out in earlier chapters, however, we have, to a large extent, overdone the business. In guarding against chill we have created an overheated artificial atmosphere in our living rooms and workrooms which is almost as harmful as the effect of the ungoverned elements themselves. The function of ventilation is to correct this oversophistication of the atmosphere, to restore conditions more nearly resembling the outdoor atmosphere when weather conditions are ideal. No system of indoor air conditioning can, however, equal the outdoor air at its best. Cool open air,

fresh and clean and in stimulating motion is the best stimulant for the skin and, with the exercise which accompanies outdoor life, one of the most useful tonics for the whole body.

Windows should, therefore, be kept open whenever it is possible to do so without harmful drafts, irrespective of other systems of ventilation. In the schoolroom it is often found most helpful to throw open the windows for five minutes in the middle of the session while the pupils move about or exercise in order to keep warm. The stimulus of the cold-air bath will more than make up for the lost time; and even in factories such a procedure may prove of practical advantage.

For the undernourished, the anemic, the "pre-tuberculous" child, the open-air schoolroom will often prove an invaluable tonic; and every large school building should be provided with a room of this sort. Exposure to unmodified winter temperatures, in cold climates, is, however, accompanied with many inconveniences and makes a demand upon the heat-producing powers of the body which must be met by special clothing and supplementary feeding. It is, therefore, unnecessary and undesirable to preach "unhousing" as a general panacea or to advocate the conversion of all

schoolrooms into open air rooms. Extreme, continuous fresh air treatment is a medicine rather than a food.

In the sleeping room, on the other hand, where the body is warmly covered, the impact of cold moving air upon the face seems to be highly and peculiarly beneficial. Windows should, therefore, be widely opened in the bedroom, even in the coldest weather, or the bed placed on a sleeping porch outside.

The Hygiene of Clothing

It will be obvious that the hygiene of ventilation and the hygiene of clothing are very closely interrelated, since both are primarily concerned with the regulation of heat loss from the body. A given atmospheric temperature may be ideal for persons clothed in a particular way while it may be too warm or too cool for those who are differently clad.

As in the case of air conditioning, the main essential in the selection of clothing is to guard against chill on the one hand and to avoid, on the other, the debilitating effect of heat and uniformity—in other words, to keep the blood vessels of the skin stimulated by moderately cool and moving air. The effect of various

fabrics depends chiefly on their power of conducting heat and of absorbing or giving off moisture—properties which, in turn, are in large measure conditioned by porosity and the amount of air held between the fibers. Wool, of course, conducts heat less readily than linen or cotton and is, therefore, warmer. It absorbs moisture more readily and gives it off less readily. In general, it seems probable, with the ample warmth provided in American dwellings, that the wearing of woolen underwear in winter is distinctly harmful and that it is better to wear the same type of underclothing the year round, with heavy outer clothing when one goes outdoors. In summer we not only need the lightest weight clothing possible but also outer clothing which is light in color, since dark fabrics may absorb twice as much heat as white ones.

The remarkable extent to which the body may become acclimated to cold—and the beneficial effect of such a process—is well illustrated by the fact that children in tuberculosis sanatoria become so hardened that they bear even the air of a very severe winter with the body practically unclothed. The enormous incidence of respiratory disease among the natives of Melanesia is attributed in large

measure to the harmful effect of civilized clothing.[4]

The Hygiene of Bathing

Bathing has, in general, a twofold objective. It serves the purposes of cleanliness, particularly when warm or hot water is used; and it also plays an important part, along with ventilation and proper clothing, in promoting the hygiene of the skin.

We have seen that one of the primary aims of air conditioning is to stimulate the blood vessels of the skin and respiratory tract so as to keep them in vigorous condition. The heat-regulating mechanism of the body, and especially its power of resisting attacks of respiratory disease, depend very largely upon the efficiency with which the nerves of the muscle cells in the walls of these tiny blood vessels respond to changes in atmospheric temperature. These muscles require exercise, just as do the muscles of the arms or legs. In a person who dresses too warmly and lives in overheated rooms, the skin blood vessels grow flabby and ineffective. Their owner grows over-sensitive to what the French

[4] *Essays on the Depopulation of Melanesia.* Edited by W. H. R. Rivers. Cambridge University Press, 1922.

call a *courant d'air* and becomes highly susceptible to colds and sore throats. Moderate clothing and cool moving air playing upon the body exercise these blood vessels and keep them in good form; but one of the best stimuli which we can apply to these important organs of the body is the cold bath.

For all who are able to react with a wholesome afterglow to the stimulus, a daily morning cold bath is one of the most useful elements in the régime of personal hygiene. Even those who find such a bath too taxing at first may generally accustom themselves to it by beginning the habit in summer. The reward will be a fuller sense of well-being for the beginning of the day and a markedly greater resistance against the ordinary respiratory diseases.

The hygiene of the skin—the stimulating to healthful activity of the heat-regulating system of the body—is one of the most important aspects of health promotion; and ventilation, clothing, and bathing are the three chief elements which contribute to its attainment.

THE END

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